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Plant Operation:

The Utilization of Sewage Sludge as Fertilizer. Report of the Committee on Sewage Disposal, American Public Health Association. By C. K. Calvert, Almon L. Fales, C. G. Gillespie, C. E. Keefer, T. J. Lafreniere, F. W. Mohlman, Willem Rudolfs, F. M. Veatch, P. J. A. Zeller and Langdon Pearse, *Chairman* 861

Layout and Plan of Operation of the Minneapolis-St. Paul Sewage Treatment Plant. By George J. Schroepfer 913

The Beautification and Irrigation of Golden Gate Park in San Francisco with an Activated Sludge Treatment Plant Effluent. By Charles Gilman Hyde 929

Supervision of Sewage Works Operation by the Engineer of Design. By G. A. Parkes 942

Industrial Wastes:

Cedar Rapids' Agreement with the Packers. By Howard R. Green 950

Packinghouse Waste and Sewage Treatment at Sioux Falls, South Dakota. By R. E. Bragstad and Leland Bradney 959

The Effects of Industrial Wastes on Sewage Treatment. By Almon L. Fales. Discussion by Arthur D. Weston 970

A Survey of Recent Developments in the Treatment of Industrial Wastes. By Willem Rudolfs. Discussion by Charles R. Hoover 998

Utilization and Disposal of Sulfite Waste Liquor. By Kenneth A. Kobe 1019

Sewage Treatment and Industrial Wastes in the Fox River Valley. By Samuel A. Greeley 1024

Operators' Reports and Suggestions:

Problems and their Answers at the Ontario Activated Sludge Plant. By H. M. Ely. 1033

Sewage Plant Operation at Santa Clara, California. By Albert J. Castro, Jr.... 1035

A Separate Sludge Digestion Operation Problem. By Earl M. Kelly 1038

Rags and Grease at the City of Los Angeles' Terminal Island Treatment Plant. By H. G. Smith 1042

Editorial:

Sludge as Fertilizer 1045

Proceedings of Local Associations:

California Sewage Works Association, Tenth Annual Convention 1047

New York State Sewage Works Association, Fall Meeting 1049

Central States Sewage Works Association, Tenth Annual Meeting 1050

The Canadian Institute on Sewage and Sanitation, Fourth Annual Convention 1053

Reviews and Abstracts:

Sewage Disposal at Barnsley. By H. D. Bell 1056

The Rationalization of Sewage Disposal. By C. B. Townend 1057

Halifax Sewage Disposal Works. Anonymous 1057

Remedying Sewer Infiltration. By N. S. Bowes 1058

The Balance of Oxygen in an Activated Sludge Tank. By N. A. Basiakina 1058

Detection and Measurement of Stream Pollution. By M. M. Ellis 1060

The Role of Enzymes in Activated Sludge and Sewage Oxidations. By W. R. Wooldridge and A. B. Standfast 1061

Relationship Between Turbidity Measurements and B.O.D. and Suspended Solid Determinations. By W. Watson and E. McG. Weir 1062

The Renaissance of the Percolating Filter. By H. N. Jenks 1063

Book Review: "Vom Wasser" 1065

References to Sewage Literature 1067

Author Index iii

Subject Index vii

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Plant Operation

THE UTILIZATION OF SEWAGE SLUDGE AS FERTILIZER *

REPORT OF THE COMMITTEE ON SEWAGE DISPOSAL, AMERICAN PUBLIC HEALTH ASSOCIATION, PUBLIC HEALTH ENGINEERING SECTION

Committee

C. K. Calvert, Almon L. Fales, C. G. Gillespie, C. E. Keefer, T. J. Lafreniere, F. W. Mohlman, Willem Rudolfs, F. M. Veatch, P. J. A. Zeller, Langdon Pearse, *Chairman.*

The purpose of this Committee report, entitled "The Utilization of Sewage Sludge as Fertilizer," is to assemble available data, so far as practicable, relating to the use of sewage sludge as fertilizer. No original research has been attempted. Acknowledgment is made to all sources quoted for whatever appeared of value for this report. To the various State sanitary engineers, sewage works operators and municipal officials who have furnished data, the thanks of the Committee are freely given. Without their hearty cooperation, the collection of the basic information would have been a difficult task in the limited time available.

The Committee has restricted its investigation to the United States and Canada, and consequently has limited its bibliography likewise.

Importance of Problem of Use of Sludge as Fertilizer

The Municipal Index (1, 2) in a survey of 1422 cities in the fall of 1930 reports the methods of sludge disposal at 398 cities and villages in the United States, as follows:

Method	Number
Sale or use as fertilizer	210
Wasting	68
Use as fill	38
Burying	23
Discharge into a body of water	18
Part used as fertilizer, remainder wasted	9
Part used as fertilizer, remainder as fill	9
Incineration	7
Part used as fertilizer, remainder incinerated	3
Lagooning	6
Transportation by scow to ocean	3
Broad irrigation	1
Part used as fertilizer, remainder lagooned	1
Part used as fertilizer, remainder buried	1
Part incinerated, remainder used for fill	1
Total Reporting	398

* Presented at the Sixty-sixth Annual Meeting of the American Public Health Association, in New York, N. Y., October 8, 1937. Released by Editor of the *American Journal of Public Health,* Dr. M. P. Ravenel.

Of the foregoing 15 methods of disposal, the first 5 (amounting to 357) comprise 90 per cent of the total. However the use of sludge as fertilizer was practiced in whole or in part by 233 or practically 60 per cent.

Soil Fertilization

To explain the function of fertilizers and various conditioners on soil for growing vegetation, a few facts are given regarding the soil and its requirements.

Soil Requirements.—The soil requirements in fertilizing for various plants has been discussed in many volumes. Among the simpler and more recent books are those of Gustafson (3) and Laurie and Edmond (4). Bear (5, 6) and Weir (7) present the subjects of fertilizers and soils respectively more completely. To those desirous of fundamental reading, Bear's book on fertilizers is worthwhile because of the historical background sketched therein.

In many states soil surveys are available, usually by counties, in more or less elaborate form, whereby the fertilizer requirements of each type of soil are made clear. There are also the soil surveys of the United States Department of Agriculture.

As regards the requirements of the soil, Laurie and Edmonds say (8):

> "The elements essential for plant growth may be divided into two groups: those which are secured freely from air and water, and those which are found in the soil or have to be added at certain intervals. The first group includes hydrogen, oxygen and carbon. The second is composed of nitrogen, phosphorus and potassium and a number of miscellaneous elements usually found in sufficient quantities in the average soil, such as calcium, magnesium, sulfur, iron, manganese and others."

Willis has compiled (9) a very complete bibliography on the references to the literature on the minor elements and their relation to the science of plant nutrition. In the foreword he summarizes the role of the various minor nutrients as follows:

(*a*) Those elements which are more or less indispensable are boron, calcium, copper, iron, magnesium, manganese, sulfur and zinc.

(*b*) Those elements which may influence plant growth but can be replaced by other elements are aluminum, arsenic, cobalt, chromium, radium, uranium, silicon, selenium, strontium, tin and lead.

(*c*) Those elements which are not beneficial to plant growth but are valuable as components of feeds and may not be supplied to animals except in the feed are iodine, chlorine, fluorine and sodium.

(*d*) Those elements which are found in soils, plants and animals but as yet there is no direct evidence that they serve any useful purpose are antimony, lithium, barium, vanadium, rubidium, titanium and zirconium.

Willis also points out (10) that boron has proven toxic and in certain percentages borax has been injurious in a fertilizer. In one soil in Southern California it has been present in sufficient amount to be

injurious to citrus and walnut trees. Mercury is poisonous to certain young plants.

Briefly, nitrogen is required by all plants, particularly where leaf development is required. Thus it is of great value in fertilizing grass, lettuce, spinach and celery. It stimulates the growth of leaf and stem.

Phosphorus is essential in many phases of plant growth. It hastens ripening, encourages root growth and increases resistance to disease (11).

Potassium is an important factor in vigorous growth. It increases resistance to disease but delays ripening and is needed for the formation of chlorophyl.

The amounts of each element depend on the soil and the crop, hence making additions of the limiting element constitutes the use of fertilizer. Various formulae are suggested for the combination of nitrogen, phosphorus and potash best suited to different crops and soils. For example, a 5–6–4 mixture may be used for lawns. This method of combining the elements in most states follows a resolution adopted in 1928 by the National Fertilizer Association, designed to standardize fertilizer terms for the entire United States, whereby by weight the first figure indicates nitrogen expressed as per cent of total nitrogen, the second is per cent of available phosphoric acid as P_2O_5, and the third is per cent of water soluble potash as K_2O. Changes in the laws of some states are necessary before these resolutions can become effective (12).

In the Southern States, for cotton, varying recommendations are given (13) by Bear:

Region	From Heavy to Light Soils
S.E. Virginia and N.E. Carolina	4–12–4 or 6–10–4
Coastal Plain of the Carolinas	4–10–4 or 5– 8–3*
Piedmont Section, Carolinas and Georgia	5–10–3 or 5–10–5*
Coastal Plain of Georgia †	3– 9–5 or 3– 9–8*
Hill and Flat Woods Region, Mississippi	6– 8–4 or 4– 8–4
Prairie Section of Mississippi	8– 8–0 or 4– 8–4
Mississippi Delta Region	Nitrogen alone ‡

* Supplemental top-dressings of nitrogen at the rate of 15 to 25 pounds of the element per acre.

† 4–8–4 for gray soils, 4–10–4 for red and brown soils.

‡ Potash to be added if troubled by disease.

These recommendations are cited to show the variation with soils and climate on a staple crop.

Similarly, on tobacco in Virginia, the Carolinas and Georgia, Bear cites (13) the recommendations of specialists:

Type of Tobacco	Pounds per Acre	From Heavy to Light Soils
Bright, flue-cured	800–1,200	3–8–5 or 4–8–6
Dark, sun-cured	600–1,000	3–8–3

In Massachusetts (14), the largest tonnage of fertilizer sold (34 per cent of the total) in the calendar year beginning July 1, 1934, was a 5–8–7 mixture. For a balanced fertilizer for lawns, Haskins (14, 15)

recommends in Massachusetts a 7–6–4 mixture, whereas Noer has recommended for grass on clay soils in Northern Illinois a 5–6–4 mixture. For lawn and gardens generally in the Middle West, a nationally known seedsman recommends 4–8–6. For general use in the home garden, 5–8–7 is suggested, whereas Noer recommended 4–8–6. These differences are slight. For general truck and market garden crops Bear (16) recommended 400 pounds per acre of a 4–12–4 analysis. The figures indicate the ranges occurring in the use of various fertilizer ingredients in general gardening practice.

A cautious text-book writer, Weir, emphasizes (17):

"No general rule can be given for fertilizing soils, since conditions are so variable and soils differ so widely in their characteristics. The only sure way of determining the fertilizer needs of a crop on any particular soil is by actual field tests."

Measure of Fertilizer Values

The measure of fertilizing value is well stated by Fraps (18):

"The value of fertilizer is considered to be chiefly due to nitrogen, phosphoric acid and potash it contains, and upon the extent to which these plant foods can be taken up by plants. While it is known that under exceptional conditions other elements have a value to crops, at the present time this need seems to occur in relatively isolated areas. The fertilizing value of sewage sludges depends upon the percentages of total nitrogen, available phosphoric acid, and water-soluble potash they contain, and also on the availability of the nitrogen in them. If the plant food cannot be taken up by plants, it obviously has no value to them."

In addition to the usual fertilizer values above cited, there is also the value of the material as a source of organic matter to the soil. Such organic matter is frequently referred to in general terms as "humus."

Humus.—Humus, according to Waksman (19), results from the decomposition of plant and animal bodies, mainly through the agency of micro-organisms, and has certain specific properties:

1. Dark brown to black color.
2. Practically insoluble in water.
3. Contains a larger amount of carbon than do plant, animal and microbial bodies. The carbon content is usually about 55 to 56 per cent, and may reach 58 per cent.
4. Contains considerable nitrogen, usually about 3 to 6 per cent. May be as low as 0.5 per cent in certain peats and as high as 12 per cent in certain subsoils.
5. Contains the elements C and N in proportions close to 10:1, but this ratio may vary.
6. Is in a dynamic condition, since it is constantly formed from plant and animal residues and is continuously decomposed further by micro-organisms.
7. Serves as a source of energy, for the development of various groups of micro-organisms.
8. Is characterized by a high capacity of base exchange.

Humus in Sewage Sludge.—Waksman states (20) that humus formation is synonymous with stabilization of plant and animal residues, from a readily decomposable or putrescible state into an innocuous form. Clearly, sewage sludge comes within the above definitions of humus.

There are at least five ways of determining humus by analysis, but no official method is available. Some sewage chemists have assumed that the volatile matter in sludge is all humus. It would be more exact to deduct at least the ether soluble matter.

Need of Organic Matter for Soil Improvement.—Dachnowski-Stokes states (21):

"The need of organic matter for soil improvement creates a problem that becomes increasingly acute. By far the most valuable constituent of a soil is its organic matter, and depletion of soil humus has become an important factor in impoverishing cultivated soils and subjecting them to erosion."

After commenting on the relatively rapid decay of the organic matter of green crops plowed in, he adds:

"There is, therefore, a general demand for a source of organic matter that would provide a satisfactory and relatively persistent material, and that would maintain improvements in mineral soils when used in greenhouses, nurseries, golf courses, parks and gardens that are seriously impoverished in their present condition."

He advocates the consideration of peat and muck as a source of such organic matter, and notes the value of peat in mixed fertilizers as a conditioner, or in composts with other plant residues and a variety of animal waste products. The bearing of these facts on the sewage sludge problem is that sewage sludge and peat have somewhat similar qualities, although as a rule peat usually contains more organic matter and less ash than sludge.

Peat varies from 9 to 75 lb. per cu. ft. dry, according to its type, and has a high water absorbing capacity. Digested sewage sludge, as removed from the air drying beds, may vary (22) from 31 to 60 lb. per cu. ft. according to the water content when dried (8 to 68 per cent).

Changes of Composition of Mixed Fertilizers

Tidmore and Simmons (23) point out that—

"during recent years many changes have occurred in the composition of fertilizers. The plant food content of most of the fertilizer materials used in mixed fertilizers has been increased and many new ones, with very high concentrations of plant foods, have appeared on the market. The sources of nitrogen for mixed fertilizers have also changed with time. For instance, in 1900, approximately 71 per cent of the nitrogen in mixed fertilizers was derived from organic ammoniates and only about 6 per cent from ammonia and its salts, whereas in 1932, only 18.3 per cent of the nitrogen in mixed fertilizers was derived from organic ammoniates and 56.4 per cent from ammonia and its salts (24). It has been necessary, therefore, to raise materially the grade of fertilizer mixtures or to dilute them with sand or other fillers."

"In the United States, the average fertilizer grade was raised from 14.8 to 18.5 per cent plant food between 1910 and 1932. Since the grade of fertilizer has not been materially raised but the plant food content of most of the fertilizer materials has been in-

creased, it is evident that more filler is required in mixed fertilizers than formerly. For example, the mixed fertilizers of the United States contained about 6.75 per cent filler in 1900, whereas they contained 15.17 per cent in 1931. The fertilizers are also more acid forming than formerly. The amount of ammonium sulfate used in mixed fertilizers of the United States increased from 4,120 tons in 1900 to 322,878 tons in 1931."

Tidmore and Simmons state (23) that nitrogen can be bought more cheaply in ammonium sulfate than in organic nitrogen. However, in their opinion ground limestone should be used in place of sand as a filler to neutralize the acidity.

Growing Use of Fillers.—Mehring and Peterson indicate (24) the growing use of fillers in mixing commercial fertilizers. In 1880, practically no filler was used. Since then fillers such as sand, limestone, phosphate rock, dolomite or coal ashes have been used in increasing quantities, rising to 1,067,015 tons in 1917 (20 per cent of the total tonnage of mixed fertilizer) and receding to 690,798 tons in 1931 (15 per cent of the total tonnage of mixed fertilizer).

Sewage Sludge as a Filler.—Because of this change in the mixing of fertilizers, a growing market has been presented for low-grade tankage, peat and heat-dried activated sludge as a source of organic nitrogen and filler. But little use has been made so far of heat-dried digested sludge probably because of its low nitrogen content.

With reference to the use of activated sludge, the Wisconsin Agricultural Experiment Station comments (25):

"It appears that the organic nitrogen carriers, because of their collodial nature and absorption capacity, exert a favorable effect on the mechanical condition of the mixtures and their use also results in a minimum loss of nitrogen because it tends to be made available as required by the plant. The inorganic forms are in the main more readily available, but are also easily lost by leaching and do not help to improve conditions for desirable bacterial activities as is done by the organic nitrogen carriers. Furthermore, some of the organic nitrogen carriers previously available have been largely diverted into stock feed, so that there is a shortage of this class of material. Apparently activated sludge is well adapted to fill this shortage."

Possible Tonnage of Sludge in the United States

In 1934, a survey was made by The Sanitary District of Chicago of all the sewage works then existing in the United States, which indicated 2,706 works treating the sewage of approximately 25,710,000 people. According to the United States Public Health Service survey in 1924 (26), the average amount of dry suspended solids in sewage was 87.7 pounds per capita per year. On this basis the total suspended matter received at the sewage works in the United States for the year 1934 was 1,128,000 tons. If 50 per cent of the dry solids are removed, and these solids lose 30 per cent during digestion, 395,000 tons of dry digested solids might be recovered. If this material contains 2 per cent nitrogen, the total quantity of nitrogen collected would be 7,900 tons per year. Even if all the suspended solids arriving at the sewage works were recovered as activated sludge, with 5 per cent nitrogen,

only 56,400 tons of nitrogen would result. But actually somewhat less than 50,000 tons of dry solids, containing about 3,100 tons of nitrogen are recovered annually as activated sludge in the United States. Based on an average of 3.7 per cent of nitrogen in the 6,820,193 tons of mixed fertilizer sold in the United States in 1936 (27), 252,347 tons of nitrogen were sold. Thus the recovery of nitrogen in sludge is only about 3 per cent of the nitrogen actually sold in mixed fertilizer.

A more recent survey (Table I) made by the U. S. Public Health Service (28) indicates that approximately 32,200,000 population were

TABLE I.—*Progress in Sewage Treatment in United States, 1932–37*

	1932	1935	1937
United States population: *			
Total	124,974,000	127,521,000	129,447 000
Urban †	69,562,000	70,833,000	72,359,000
Population tributary to sewage treatment plants	21,500,000	28,400,000	‡37,200,000
Total tributary population:			
Per cent of total United States	17	22	29
Per cent of urban United States †	31	40	51
Per cent of sewered United States	35	42	52
Tributary to plants in incorporated places:			
Tributary to all plants	19,500,000	25,900,000	‡55,200,000
Tributary to primary treatment plants §	——	12,100,000	16,000,000
Tributary to primary and secondary treatment plants §	——	13,800,000	19,200,000
Number of plants, incorporated places:			
Total	2,900	3,200	3,700
Primary treatment	1,700	1,800	2,000
Primary and secondary treatment	1,200	1,400	1,700

* Population estimates are for July 1 of each year, and are based on estimates of total population and farm population by the Bureau of Census and Bureau of Agricultural Economics respectively.

† Urban population includes only the population of incorporated places of more than 2,500.

‡ Includes 5,000,000 population served by plants under construction.

§ "Primary treatment" is used to mean settling or the equivalent. It does not include screening. "Secondary treatment" is used to mean further treatment of the effluent from the primary process.

Data collected and analyzed by the United States Public Health Service. Second Report of the Special Advisory Committee on Water Pollution, p. 4 (1937) (Ref. 28).

served by treatment works in 1937. An additional 5,000,000 will shortly be served by works under construction. The total represents more than half the entire urban population of the United States, served by approximately 3,700 plants. The quantity of suspended matter in the sewage is approximately 1,631,400 tons annually from the total of 37,200,000 persons. On the same assumptions as before, after digestion approximately 571,000 tons of dry sludge would remain, containing 11,420 tons of nitrogen, on a 2 per cent nitrogen basis.

A comparative summary of recent surveys of the number of sewage works in the United States from various sources is given in Table II.

TABLE II.—*Number of Sewage Works in United States*

Survey	Year	Number of Plants	Population	
			Census	Served
U. S. Public Health Service *	1932	2,900	21,500,000	
The Sanitary District of Chicago	1934	2,706	25,710,380	21,072,745
Engineering News-Record †	1935	3,697	22,200,000	
U. S. Public Health Service *	1935	3,200	28,400,000	
U. S. Public Health Service *	1937	3,700	37,200,000	

* Second Report of the Special Advisory Committee on Water Pollution, p. 4 (1937) (Ref. 28).
† *Engineering News-Record*, Aug. 15, 1935 (29).

TABLE III.—*Analyses of Digested Sludge, Imhoff and Separate Digestion Plants*

City	Analysis on Dry Basis					Moisture—Per Cent	
	Per Cent						
	Mineral	Volatile	Nitrogen as N	Ether Soluble	Phosphoric Acid *	Removed from Beds	Sacked
Connecticut:							
Greenwich I	51	49	2.38	5.88		67	
II	51	49	2.79	4.10		42	
III	48	52	3.56	3.28		39	
IV	51	49	2.08	4.75		58	
Michigan:							
Grand Rapids		38–45	2.3–3.3	2			
New Jersey:							
Atlantic City	55	45	2				10
New York:							
Middletown	57	43	2.4	3.9	0.81	56	
Rochester	54	46	2.1	11		56	
Schenectady	35	65	0.8	5.2		55	
Ohio:							
Dayton	54.5	45.5	3.53	6.8			8
Delphos	67	33	1.75		2	83	
Lakewood			0.8				
Norwalk	60	40	2.25				
Toledo	51.5	48.5	3.0			5–10 †	

* As P_2O_5.
† Dried under glass.

Types of Sludge

In general, sludges may be divided into four classes:

(1) Settled (also called fresh).
(2) Digested (after settling).
(3) Activated.
(4) Digested activated.

Table IV.—*Analyses of Digested Sludge, Tank and Trickling Filter Plants*

City	Analysis on Dry Basis					Moisture as Removed from Beds Per Cent
	Per Cent					
	Ash	Volatile	Nitrogen as N	Ether Soluble	Phosphoric Acid *	
California:						
Oxnard	58	42	2.60			18.3
San Bernardino	40	60	2.75			
Signal Hill	60	40	1.3			6.0
Kentucky:						
Lexington	46	54	2.8	11.9		60
Maryland:						
Baltimore	40	60	2.5	10		60
Massachusetts:						
Brockton	74	26	1.0			29
Fitchburg	58	42	2.0	7.7		36
Worcester						
Primary	57	43	2.7			
Secondary	52	48	3.4			
Michigan:						
Battle Creek	40–45	52–57	3–4			27–42
Flint	55	45	2.5	8		45
Pontiac	51	49	2.0			
New Jersey:						
Freehold	45	55	3.0			
Plainfield	50	50	3.9	6.0		
New York:						
Rochester						
Brighton	68	32	1.9			
Schenectady	35	65	0.8	5.2		55
Ohio:						
Akron	54.5	45.5	1.73	4.97		40.1
Canton	40	60	1.5			
Cleveland S	55.7	44.3	3.05	13.2		57
Columbus						
Septic tanks	73	27	1.34	6.8		40
Imhoff tanks			2.8			37
Delaware	36	64	3.6		1.6	
Marion	44	56	3.2		2.1	
Wisconsin:						
Madison	33–40	67–60	3–4.5	10		40–70

* As P_2O_5.

Sludge may be obtained directly from raw sewage and undergo any one of the above four treatments, or it may be precipitated from the raw sewage with the aid of various chemicals, and then pass through any one of the four treatments. Further, when trickling filters are used, a secondary sludge or "humus" is obtained by settling the effluent of the filter. This sludge is generally mixed with the primary sludge and passed through whatever treatment is given.

Fertilizing Values in Sludge

From the returns from 417 sewage treatment works, a few analyses were obtained, compiled in Tables III, IV, V and VI, and classified under the headings of—

Digested Sludge, Imhoff and Separate Digestion Plants
Digested Sludge, Tank and Trickling Filter Plants
Activated Sludge, in Plant or Heat Dried
Activated Sludge, Digested or Lagooned.

Table V.—*Analyses of Activated Sludge, in Plant or Heat Dried*

City	Analyses on Dry Basis					
	Per Cent					
	Mineral	Volatile	Nitrogen as N	Ether Soluble	Phosphoric Acid †	Potash
San. Dist. Chicago						
Calumet						
Old	39	61	4.3	6.9		
New	45–55	45–55	2.5–4.0			
Des Plaines			4.5–5.5		2–4	
North Side ‡	31–48	52–69	3.6–5.2		2–2.7	
Corn products			7.0–8.0		6–7	
Packingtown	37	63	4.2	6.0	2.7	
Tannery	48	52	3.0			
Houston	37	63	5.5		1.9	
Indianapolis	35	65	4.8			
Milwaukee	20–25	75–80	6.0	5.0	3.2–3.5	0.5–0.75
Pasadena	25–30	70–75	6–6½	10–12		
Guaranteed	30	70	6		3	0.30
State *			6.62		3.29	0.27

* Six analyses by California Dept. Agriculture, 1935.
† Total as P_2O_5.
‡ Average of 10 months in 1936 as pumped to West Side Works.

Although there is considerable variation in these sludges the data clearly point to a higher nitrogen content in the heat-dried activated sludge than in the others, raw or digested. But little data are available on the nitrogen content of fresh sludges. In the 39th Street Testing Station of the Sanitary District of Chicago in 1910–1914, freshly removed sludge from settling tanks showed a nitrogen content ranging

TABLE VI.—*Analyses of Activated Sludge, Digested or Lagooned*

Municipality	Analyses on Dry Basis					Moisture as Removed from Beds Per Cent
	Per Cent					
	Mineral	Volatile	Nitrogen as N	Ether Soluble	Phosphoric Acid *	
Collingswood, N. J.	40	60	4.35			18
Durham, N. C.	61	39	2.56			
Elyria, Ohio	50	50	2.5	3.5		
Findlay, Ohio	59	41	2.5			30–60
High Point, N. C.	45	55	2.8			
Indianapolis, Ind.†	54	46	2.4	5.4		75.8
‡	35	65	4.8	7.8		
Los Angeles, Cal.	53	47	3.0	7.5	3.6	20–45
New Canaan, Conn.†	45	55	2.6	2.57		20–30
Phoenix, Ariz.	50	50	4.0			20–35
Pomona, Cal.			2			15
Richmond, Ind.		50				
Rockville Center, N. Y.	45	55	2			38
San Antonio, Tex.	43	57	2.8		1.35	41
San Francisco, Cal. Golden Gate Park	55–70	45–30	2.9–5			

* As P_2O_5.
† Aerated and lagooned.
‡Activated.

TABLE VII.—*Indianapolis Sanitary District. Average of Daily Composited Sludge Samples*

	Per Cent on Dry Basis						
	Primary Sludge			Activated Sludge			
	Total Organic Nitrogen	Ether Soluble	Ash	Total Organic Nitrogen	Ether Soluble	Ash	Iron as Fe
1926	2.64		29	5.03		30.0	
1927	2.72		33.0	4.65		36.0	
1928	2.82		29.42	5.07		34.95	2.09
1929	2.94	11.65	30.61	4.44	8.78	37.50	2.22
1930	3.14	10.81	25.32	5.16	9.10	32.02	1.93
1931	3.04	11.44	24.10	5.05	8.46	34.68	1.31
1932	3.41	11.76	23.93	4.74	7.90	36.98	1.18
1933	3.84	10.78	25.05	4.14	8.07	34.73	1.07
1934	3.08	7.31	24.40	4.92	6.48	33.96	1.09
1935	2.82	7.44	21.26	4.54	5.73	36.79	1.20
1936	2.88	21.67*	25.18	4.80	8.33*	36.13	1.42†

* Chloroform soluble
Ash on primary sludge chloroform soluble 9.47 per cent.
Ash on activated sludge chloroform soluble 3.06 per cent.
† Plain aeration sludge.

from 1.2 to 3.0 per cent on a dry basis, averaging 1.9 over three years. Over two years, the Imhoff tank sludge averaged 1.69 per cent. Analyses from the Indianapolis Sanitary District from 1926–1936 inclusive (Table VII) show the primary sludge as lower in total organic nitrogen and higher in ether soluble than the activated sludge from the Indianapolis works.

TABLE VIII.—*Fertilizer Constituents of Sewage Sludge from Texas Municipalities*

Municipality	Sludge	Per Cent					
		Nitrogen	Total Phosphoric Acid	Insoluble Phosphoric Acid	Available Phosphoric Acid	Potash	Water
Waco	Digested *	4.03	1.20	.42	.78	.09	7.64
College Station	Digested	2.99	2.48	—	—	.19	5.48
Fort Worth	Digested	1.85	.75	—	—	—	—
Laredo	Digested	.88	.80	—	—	1.44	2.69
Brownsville	Digested	1.29	1.72	.64	1.08	.02	4.89
Jacksonville	Digested	1.42	.47	.26	.21	.04	5.03
College Station	Digested	2.46	1.44	.30	1.14	.20	5.26
College Station	Digested †	1.83	1.32	.26	1.06	.17	6.17
San Benito	Digested	1.63	1.28	.24	1.04	.20	4.65
Greenville	Digested	1.61	1.79	.28	1.51	.07	17.11
Waco	Digested	2.62	3.74	1.44	2.30	.07	6.94
El Paso	Digested	2.27	1.38	.31	1.07	.08	4.36
Dallas	Imhoff	1.79	1.40	.63	.77	.11	3.65
Alpine	Digested	2.96	1.64	—	—	.53	6.21
El Paso	Digested	1.48	2.64	—	—	—	—
El Paso	Digested	.55	.53	—	—	—	—
San Antonio	Digested	3.49	2.92	—	—	—	—
Average digested sludge (16)		2.09	1.63	.46	1.13	.26	6.37
Houston	Activated	3.59	2.69	.72	1.97	.22	5.75
Houston	Activated	5.54	—	—	—	—	4.58
Houston	Activated	4.87	—	—	—	—	4.15
Milwaukee, Wis.	Milorganite	5.17	2.59	—	—	—	5.18
Houston	Activated, dried	5.14	2.85	—	—	—	—
Houston	Activated, 20 mesh	5.29	—	—	—	—	—

From Bull. 445, Texas Agricultural Experiment Station (Ref. 18, p. 7).
* Fresh solids.
† Septic tank.

Fraps investigated (18) the fertilizer constituents of Texas sewage sludges (Table VIII) and found the digested sludge contained from 0.55 to 2.99 per cent of nitrogen, with an average of 2.09 per cent. The total phosphoric acid varied from 0.47 to 3.74 per cent, averaging 1.63 per cent.

A considerable variation may occur in the composition of digested sludge. From the reports (30) of the Grand Rapids (Michigan) works,

Table IX has been compiled, which shows the variations in nitrogen, phosphorus, lime and humus from 1931 to 1936. Not enough determinations were given of potash, silicates or iron and aluminum oxides to draw any conclusions.

TABLE IX.—*Fertilizing Constituents in Digested Sludge at Grand Rapids, Michigan*

	Expressed in Per Cent on Dry Basis				
	1931–2	1932–3	1933–4	1934–5	1935–6
Nitrogen as NH_3					
Maximum	2.16	2.94	3.05	4.47	
Minimum	0.18	0.92	2.06	1.29	
Average	1.81	2.11	2.58	3.36	2.99
Phosphorus as P_2O_5					
Maximum	4.17	4.02	2.83	3.00	
Minimum	0.93	0.81	1.35	1.74	
Average	2.30	2.16	1.84	2.58	1.79
Potash as K_2O					
Average			0.30		
Lime					
Maximum		26.9	28.2		
Minimum		6.5	11.1		
Average		16.9	18.9		18.6
Humus					
Maximum	36.2	54.1	44.6		
Minimum	24.0	20.7	24.7		
Average	29.8	32.5	35.7		36.7
Silicates				32	
Fe and Al Oxide				4.6	

Data from annual reports of the periods above noted (30).

Non-Fertilizer Constituents of Sludge

Supplementing Table VIII, Fraps showed (18) the non-fertilizing constituents of various Texas sewage sludges (Table X). The variations in the ash and grease are of interest.

Comparison of Digested Sludge with Farm Manure

DeTurk believes (31) that in its percentage content of fertilizer constituents, in their relative availability and in the physical nature of the material, digested sludge is somewhat comparable to farm manure, but "the most important differences in the two materials are that the more easily decomposable nitrogen compounds of the sludge have been more completely removed by the digestion progress than is the case with manure, leaving a nitrogenous residue of lower availability, and that

TABLE X.—*Non-fertilizer Constituents of Sewage Sludge from Texas Municipalities*

Municipality	Sludge	Per Cent of Dry Solids							
		Ash	Iron and Aluminum Oxides	Magnesia	Lime	Insoluble Ash	Pentosans	Grease	Crude Fiber
Waco	Digested *	33.43	5.92	.43	6.99	17.55	3.18	8.39	4.71
Laredo	Digested	76.46	4.67	.47	7.12	63.46	.69	4.13	3.23
Brownsville	Digested	—	7.48	.80	8.30	52.41	.93	3.48	—
Jacksonville	Digested	—	13.82	.12	4.59	54.46	.66	14.87	—
College Station	Digested	42.06	6.59	.49	2.01	30.22	1.96	16.98	11.41
College Station	Digested †	47.68	5.72	.35	3.12	38.68	2.55	8.08	15.15
San Benito	Digested	61.97	8.86	1.10	6.49	41.74	.98	7.58	4.84
Greenville	Digested	55.38	7.55	.27	2.58	45.66	1.34	5.13	5.06
El Paso	Digested	45.20	5.36	1.18	9.71	28.59	1.30	16.20	4.44
Dallas	Imhoff	47.48	4.62	.11	4.49	34.15	3.06	15.39	13.39
Alpine	Digested	51.48	7.33	.02	4.47	37.49	1.59	8.67	8.41
Houston	Activated	32.48	6.03	.08	.43	24.77	1.81	7.79	11.20
Houston	Activated	35.50	6.52	.66	.92	27.92	1.91	12.13	7.39
Milwaukee, Wis.	Milorganite	31.81	—	—	—	—	2.58	5.61	5.73
Waco	Digested	53.30	9.58	.40	9.77	30.42	2.24	5.09	8.23

From Bull. 445, Texas Agricultural Experiment Station (Ref. 18, p. 8).
* Fresh solids.
† Septic tank.

TABLE XI.—*Fertilizing Ingredients in Sludge and Various Manures and Organic Nitrogenous Materials*

Material	Per Cent on Dry Basis		
	Nitrogen as N	Phosphoric Acid	Potash
Digested settled sludge	0.8–3.5		
Digested settled with trickling filter sludge	1.0–4.5		
Digested activated sludge	2.0–4.8		
Heat dried activated sludge *	6.1	2.4	0.13
Fresh horse manure	0.6	0.3	0.6
Fresh cow manure	0.5	0.2	0.5
Fresh sheep manure	0.8	0.4	1.0
Fresh poultry manure	1.3	1.8	0.9
Commercial pulverized:			
Sheep manure	1.2–2.5	1.0–2.00	2.0–4.0
Cattle manure	1.6–2.1	1.0	1.0
Animal tankage	5–10	7–16	
Blood	9–13	0.5–14	
Fish scrap	6.5–10	5–10	
Cottonseed meal	6.0–7.4		

* From Milwaukee Sewage Works.
NOTE: This table is largely taken from Sykora (Ref. 32) and Haskins (14).

the potash, being mostly water-soluble, has been largely washed out of the sludge, while it is retained in the manure."

Typical analyses are shown in Table XI for various fertilizing materials, including sludge, horse, cow, sheep and poultry manure, animal tankage and blood.

Value of Activated Sludge

For many reasons, most authorities have agreed that heat-dried activated sludge is a different type of material from digested sludge and that it has considerable value in agriculture.

DeTurk (33) summarized his opinion:

"Its increased content of plant food substances over settled or digested sludge has encouraged many investigators to study its value as a fertilizer. Activated sludge, due to a short-time exposure to bacterial action under oxidative conditions, retains most of its organic solids, is fairly low in ash (30 to 34 per cent) and its 5 or 6 per cent of nitrogen is 40 to 50 per cent as readily available to growing crops as is that in nitrate of soda, the nitrogen carrier usually used as a standard for comparison. It may be directly used in the moist condition, or dried and ground for use alone or as a constituent of mixed fertilizers."

Bear stated (34):

"Activated sludge is a high-grade organic carrier, of nitrogen that is very useful in intensive agriculture for its buffering effect and its water-retaining capacity, as well as for its content of fairly available nitrogen."

Variations in Results

There is a considerable variation in the nitrogen content of sewage sludge, even at one plant, as evidenced by the figures given by Rumsey (30) at Grand Rapids (Table IX). It is probable that at a sewage works operated on a separate system of sewers, reasonably free from storm water leakage and infiltration, a more uniform nitrogen and organic matter content and a higher organic content will be found than on a combined sewer system. Likewise, there is a considerable variation in the nitrogen of raw or heat-dried activated sludge produced by the various plants in the United States (Table V). The characteristics of the sewerage system may play a considerable part in this variation as well as the operation of the plant.

Past History of Sludge as a Fertilizer

Grease Content.—In the past, particularly before the digestion of sewage sludge was commonly practiced or well understood, sludge was applied to fields in a wet form, or as a filter cake, with its original or fresh grease content. This sludge often proved difficult for the soil to absorb. Both digestion and the activated sludge process, with a few exceptions, reduce the ether-soluble content until it is unobjectionable to the agriculturist. In general, ether-soluble matter of animal or vegetable origin as found in sewage sludge does not appear objectionable. Oils or grease of mineral origin, however, may prove troublesome.

Bach and Frank (35) discuss the composition of fresh and decomposed sludge and conclude that the physical quality or character of the sludge is equally as important as the nitrogen content. In fresh sludge, the grease and fibrous material cause the earth to become impervious. On the other hand, decomposed sludge contains less fat and fibrous material. Further, the fat is finely divided and uniformly distributed through the sludge and is not an appreciable hindrance to percolation. The decomposed sludge dries quickly and remains porous when dry. Hence, when digested sludge is used as a fertilizer, the porosity of the ground is not adversely affected.

pH of Digested Sludge.—The pH of digested sludge is reported by a few, varying from 6.8 to 8.0. The pH for best digestion should be on the alkaline side. To obtain the best results, most soils should also be alkaline. There are, however, a few groups of shrub and plants which prefer a slightly acid soil. Rudolfs notes that sludge on aerobic decomposition in the soil produces acidic conditions and has found it becomes necessary to add lime to prevent burning, especially when the sludge is used in greenhouses.

Availability of Nitrogen.—The availability of the nitrogen in fertilizer materials is approached from two angles, one based on laboratory tests and the other on growing tests, whether in the field or in pots. Experts differ as to the value of various chemical or bio-chemical tests in determining the quality of organic nitrogen. However, field or growing tests are highly rated. For convenience of fertilizer control, certain approved methods of inspection and analyses have been developed and adopted by the Association of Official Agricultural Chemists. "In the case of nitrogen, determinations are made of the quantities each of nitrate, ammonia and organic nitrogen. The organic carrier is further subjected to tests of its quality by the use of the alkaline or neutral permanganate solutions, which give a fairly satisfactory clue as to the availability of its nitrogen" (36).

Hatfield discusses (37) the problem from both viewpoints and concludes from pot cultures that activated sludge was superior to dried blood, gluten meal or inorganic nitrogenous fertilizer when applied to sand. In garden experiments, activated sludge produced a still larger increase in growth of lettuce and radishes. Activated sludge also stimulated corn and cucumbers.

Fraps reports (18) from the Texas Agricultural Experiment Station very complete investigations on the relative availability of the nitrogen in digested sludge, as compared with other forms of nitrogen fertilizer. His results with pot cultures are summarized by DeTurk (31) in Table XII.

The results were checked by analysis of the corn plants grown to determine the proportion of added nitrogen actually taken up by the crop.

DeTurk states (31) that the studies of Fraps indicate that the availability of the nitrogen of digested sludge varies around one-fifth to one-fourth the value of that in nitrate of soda and that the availability of the nitrogen of heat-dried activated sludge is slightly below half that of nitrate of soda.

TABLE XII.—*Effects of Forms of Nitrogen on Growth on Corn Plants*

	Soil					Ave.
	A	B	C	D	E	
Average yield, dry wt., without nitrogen, gms.	4.5	3.9	3.9	6.9	7.7	5.4
Increase for nitrate of soda, gms.	11.6	11.6	10.3	16.6	13.4	13.7
Increase for nitrate of soda rated at 100 for comparison	100	100	100	100	100	100
Effectiveness of cottonseed meal relative to nitrate of soda at 100	42.2	48.3	52.4	32.1	53.0	44.7
Effectiveness of digested sludge relative to nitrate of soda at 100	20.0	13.8	12.6	29.5	47.7	24.1

DeTurk then concludes (31) that "activated sludge due to a short time exposure to bacterial action under oxidative conditions retains most of its organic solids, is fairly low in ash and its 5 or 6 per cent of nitrogen is 40 to 50 per cent as readily available to growing crops as nitrate of soda."

Haskins, Walker and Goodwin made (38) a few pot experiments to determine the nitrogen availability of processed low-grade materials and sewage sludge, including tests on Worcester, Massachusetts, Imhoff tank sludge (containing 2.75 per cent nitrogen, of which 0.62 per cent was in ammoniacal form) and Milorganite (containing 5.43 per cent nitrogen, of which 0.45 per cent was in water-soluble organic form). Two sets of tests were run, one to show the availability of total nitrogen and another to show the availability of water-soluble nitrogen. Equal amounts of nitrogen were applied to all pots:

Source of Nitrogen	Average Relative Nitrogen Availability		Comparative Nitrogen Activity by the Chemical Methods	
	Dried Blood at 80			
	Basis Dry Matter Yield	Basis Nitrogen Recovered	Alkaline Permanganate Method	Neutral Permanganate Method
Series I, Unwashed:				
Dried blood	80.00	80.00	79.34	99.20
Milorganite	60.60	57.41	56.22	82.58
Imhoff tank sludge	46.56	42.64	61.09	65.82
Series II, Washed:				
Dried blood	80.00	80.00	70.60	97.80
Milorganite	83.52	85.03	45.00	87.60
Imhoff tank sludge	47.46	43.86	46.00	82.80

NOTE: Unwashed means the original material. Washed designates the material has been freed from water-soluble nitrogen by successive washings with water.

Bear states (39):

"With soils that are very open-textured, organic sources of nitrogen are to be preferred, except as applications of the more soluble forms may be made from time to time during the crop season. Where it is feasible to apply the nitrogen some days in advance of planting the crop, it is possible so to regulate this time of application that the effects of the nitrogen of the several carriers of the element may be more or less equalized, assuming that the soil is of the average type and the conditions in the soil are favorable for bacterial processes. Each material has certain characteristics which are disadvantageous under one or another condition as to the soil, the climate or the crop."

The field tests on the availability of nitrogen will be discussed later under the various topics. However, by far the greater mass of detailed data is available for activated sludge only, and but little for digested sludge, probably because of its low content of nitrogen.

Presence of Weed Seeds.—Adequate digestion seems to provide a sufficient period of retention to destroy the usual weed seeds. However, the tomato seed may persist, but usually in very small amounts. Viehl reports (40) tests with various seeds, and found that apart from tomato, hemp or thick shelled seeds, well digested sludge should contain no seeds capable of germinating. The heat-drying of activated sludge appears to destroy the germinating power of seeds. Some operators report that passing sludge through a hammermill is effective in destroying tomato seeds.

Loss of Nitrogen in Open Air Drying Beds.—Where digested sludge is dried on open air beds, there may be a loss of nitrogen, particularly where the sludge has been washed by frequent rains when drying. There is also a loss if air-dried sludge is stored and exposed to the elements. At the 39th Street Testing Station of The Sanitary District of Chicago, there was usually a loss of nitrogen after prolonged storage, together with a decrease in the volatile content. At the Stockyards Testing Station of The Sanitary District of Chicago, a similar result was noted (41), regarding which the following comment was made:

"Typical analyses of the changes in nitrogen, fat and volatile content of air-drying sludges show that after 2 to 4½ months of drying on the sludge beds and on the ground, the sludges and scums from all sources consistently decrease in percentage of volatile constituents. This may be due in part to leaching out of the volatile matter by the rains, but in the main it represents true mineralization or volatilization of the organic contents of the sludge. The reduction in percentage of volatile matter varied from 4 to 34 per cent, the well-digested Emscher sludge and the sludge from chemical precipitation showing in general the smallest loss of volatile matter. The latter sludge, containing a large volume of iron hydrate, is initially lower in volatile matter than the other fresh sludges. In some cases a perceptible decrease in volatile content was noted after but a brief period of drying.

"In general, the nitrogen content showed a decrease after protracted drying, though not universally. The occasional increase found may be due to lack of representative sampling as an actual increase would hardly be expected. A loss in fat was noted consistently when this determination was made on the dried sludge."

Effect of Trade Wastes.—Little data are available on the effect of trade wastes on the value of sludge as fertilizer. From the questionnaires sent out by the Committee, only one town (East Rutherford, N. J.) reported that digested suldge was buried because it contained

excessive quantities of trade waste. It is possible that where the sewage contains a large amount of pickling liquor wastes from metal working industries, particularly copper, the sludge might be detrimental to vegetation.

Changes Produced by Digestion

Heukelekian (42) gives (Table XIII) the changes which take place in the decomposition of the organic constituents of sludge, as well as the chemical nature of the organic complexes found in the sludge. The humus in sludge consists predominantly (43) of protein, lignin and fat, with some admixture of hemi-celluloses and water-soluble substances. In the decomposition of the organic constituents in sewage and sludge, the greatest relative reduction takes place in the cellulose, fats and hemicellulose complexes, in the order named; the greatest relative increase was found to occur in the lignin fraction (42, 44).

Table XIII.—*Chemical Composition of Solids in Raw and Digested Sludge*

Per Cent of Dry Material

Determination	Raw Sludge	Digested Sludge
Ether—soluble fraction	34.4	8.2
Cold and hot water soluble *	8.5	5.5
Alcohol—soluble	2.5	1.6
Hemicelluloses	3.2	1.6
Cellulose	3.8	0.6
Lignin	5.8	8.4
Protein	27.1	19.7
Ash	24.1	56.0

After Waksman (43) and Heukelekian (42).
* Water-soluble ash not accounted for; hence results are higher than they should be.

DeTurk (31) also points out the effect of digestion upon the composition of sludge, as illustrated by laboratory experiment of Rudolfs (45), who analyzed fresh, partly digested and digested solids from the same plant (Table XIV).

The lowering of the nitrogen content and of its availability, the destruction of considerable grease and some fiber, and the gain in ash are all obvious in these data. Rudolfs states that the sewage used in this experiment was abnormally high in nitrogen content, the fresh solids usually containing 3.5 to 4.0 per cent and the ripe sludge about 2.7 per cent nitrogen. From the analyses of 18 samples of sludge from various cities in the United States, where digestion was from poor to good (Table XV), Rudolfs classified poorly digested sludge as averaging 2.44 per cent nitrogen and 36.5 per cent ash, and well digested as averaging 2.02 per cent nitrogen and 53.1 per cent ash.

In each pair of samples from the same place, the more fully digested sludge contained less nitrogen. The ash of digested sludge is to a considerable extent acid-insoluble and is of no fertilizer value.

TABLE XIV.—*Effect of Digestion on Composition of Sewage Solids*

Results in Per Cent of Dry Solids

Determination	Fresh Solids	Partly Digested Solids	Digested Solids
Nitrogen			
Total	4.81	3.98	3.55
Insoluble	4.14	3.61	3.41
Soluble	0.67	0.37	0.14
As NH_3	—	—	0.09
Soluble organic	—	—	0.05
Active insoluble	0.98	1.89	1.57
Inactive insoluble	1.16	1.71	1.84
Ether extract	15.11	7.79	6.83
Crude fiber	6.01	5.55	5.50
Ash	25.70	37.90	42.62
Per cent of the total nitrogen which is inactive-insoluble	24.0	43.0	52.0

From Rudolfs (45).

TABLE XV.—*Analysis of Sludge from Different Treatment Works Made by New Jersey Agricultural Experiment Station*

Place	Total N	Ash	Degree of Digestion
Trenton, N. J.	1.18	51.7	Good
Rochester, N. Y.	1.96	59.1	Good
Schenectady, N. Y.	1.86	56.9	Fair
Schenectady, N. Y.	1.97	44.1	Poor
Fort Worth, Tex.	6.77	31.5	Poor
Fort Worth, Tex.	2.07	48.4	Fair
Marion, Ohio	2.70	48.1	Fair
Marion, Ohio	2.49	40.9	Good
Baltimore, Md.	2.48	32.1	Poor
Baltimore, Md.	2.18	50.5	Good
Portsmouth, Ohio	0.63*	81.9*	Much sand
Chambersburg, Penn.	2.53	38.2	Poor
Mount Alto, Penn.	1.70	41.2	Fair
Lebanon, Penn.	2.68	40.4	Fair
Worcester, Mass.	2.97	36.9	Fair
Chicago, Ill.	1.67	58.4	Good
Antigo, Wisc.	2.09	55.2	Good
Plainfield, N. J.	3.16	37.2	Fair
Plainfield, N. J.	2.56	49.8	Good
Average	2.28	45.4	

* Left out of average.
From Rudolfs (45).

CHANGES PRODUCED BY THE ACTIVATED SLUDGE PROCESS

In the activated sludge process, the solids are usually retained in the treatment tanks for one to two weeks. During this period the fresh solids undergo certain changes in composition. The nitrogen increases.

The fats decrease markedly. The carbon also decreases. The changes can best be seen in Table XVI derived from Mohlman (46), which shows the results after various periods of aeration, in laboratory tests.

A different phase is illustrated by the data from a working plant taken from the annual reports of the Indianapolis Sanitary District, showing the analyses of the primary and activated sludge (Table VII). The primary sludge is the heavier suspended matter, and does not pass to the aeration tanks. This is lower in total organic nitrogen, and higher in ether-soluble matter, and lower in ash than the activated sludge.

TABLE XVI.—*Changes in Composition of Sludge During the Accumulation of Activated Sludge*

Days Aeration	Dried Sludge				Total Number of Fillings	Aeration Period Hrs.	Air, Cu. Ft. per Gal.
	Per Ct. Nitrogen	Per Ct. P_2O_5	Per Ct. Fat	Per Ct. Carbon			
¼	2.94	1.70	22.9	44.2	1	5.0	1.15
1	4.29	2.27	—	43.8	5	4.4	1.40
4	4.41	2.66	18.1	42.4	14	6.5	1.72
5	5.03	2.77	16.4	40.1	18	4.5	1.20
6	5.08	3.32	14.6	40.0	22	4.5	1.60
7	5.57	3.46	13.0	40.9	26	4.5	1.68
8	5.66	3.33	11.4	40.4	30	4.5	2.00
11*	4.93	2.77	13.0	38.6	35	6.2	2.32
12	5.30	2.88	12.1	39.0	39	4.5	1.55
13	5.13	3.03	10.9	—	43	4.5	2.32
14	5.52	3.11	9.6	—	47	4.5	2.12

* Sludge alone aerated.
From Mohlman (46). Tests made in 1916 at Illinois State Water Survey.

DIGESTED SLUDGE

The 1934 survey of The Sanitary District of Chicago indicated that there were in the United States over 800 sewage treatment works which digest sludge (exclusive of the activated sludge plants and septic tanks). These are of all sizes, serving a wide range of population. It is difficult to ascertain what is done with the sludge at all these plants. However, it is certain that in many a small plant air-dried digested sludge is being utilized by neighboring agriculturists. While some plants are moving 100 per cent of their production, there are many where only 10 to 25 per cent is now diverted to agriculture.

The record at Baltimore from 1915 to 1936 inclusive is shown in Table XVII. The amount of sludge taken by neighboring truck farmers has varied from year to year. During the period from 1915 to 1923, when a charge was made, the amounts taken were comparatively low (47) particularly when air-dried sludge was delivered to the private fertilizer plant for heat drying. Since 1927, with free sludge and loading, the amount yearly has risen to a peak in 1930 and declined to 1936. Originally a charge was made of 25 cents per load of 1 to 2 tons. A

TABLE XVII.—*Quantity and Character of Air-dried Digested Sludge, Back River Sewage Treatment Works, Baltimore, Maryland*

Year	Sludge Applied Cu. Yd.*	Air-dried Sludge Removed			Liquid Sludge Taken by Farmers Cu. Yd.
		Total Cu. Yd.†	Heat Dried Cu. Yd.	Taken by Farmers Cu. Yd.	
1915	47,010	16,546		1,313	7,309
1916	53,040	16,553	6,803	835	4,007
1917	51,029	14,520	3,289	1,483	839
1918	64,025	14,151	9,521	2,485	460
1919	59,886	18,108	6,261	—	16
1920	57,223	22,590	4,307	1,537	46
1921	52,375	15,601	631	6,597	6
1922	61,796	22,258	7,057	6,272	24
1923	73,008	14,009	807	13,431	1,130
1924	58,745	15,530		12,160	
1925	84,558	20,981		7,155	
1926	98,615	25,703		6,121	
1927	140,433	21,792		6,141	
1928	111,213	25,172		19,946	
1929	109,929	16,732		13,120	
1930	87,566	24,072		38,229	
1931	96,766	21,364		36,223	
1932	80,264	36,766		34,740	
1933	107,695	36,880		28,375	
1934	110,104	34,861		20,577	
1935	106,186	25,642		21,487	
1936	104,618	32,477		21,184	

* Nominally contains 90 per cent moisture.
† Nominally contains 68 per cent moisture.

falling off in sales occurred when the price was increased to 35 cents. Finally no charge was made for loading or sludge. Schaetzle (48) gives the revenue received from 1914 to 1920 (Table XVIII).

TABLE XVIII.—*Revenue from Sewage Sludge at Baltimore*

Year	From Farmers	From Drying Plant by Contract	Total
1914	$1,931	—	$1,931
1915	2,243	—	2,243
1916	1,098	$1,592	2,690
1917	346	28	374
1918	345	2,323	2,668
1919	309	1,558	1,867
1920	233	1,275	1,508

At the West Side Works of The Sanitary District of Chicago, Erickson (49) gives some figures on sludge production (Table XIX) in large Imhoff tanks.

TABLE XIX.—*Quantity and Character of Digested Sludge, West Side Sewage Treatment Works, The Sanitary District of Chicago*

Year	Sludge Applied		Sludge Removed—Air-dried				
	Cu. Yd.	Moisture Per Cent	Cu. Yd.	Per Cent			Thickness Inches
				Moisture	Volatile	N	
1932	216,000	94.4	40,300	38.8	44.4	2.24	3.8
1933	288,000	94.1	43,700	46.5	46.2	2.37	3.6
1934	286,000	94.1	36,500	41.0	45.5	2.18	3.1
1935	217,000	92.7	36,800	47.2	43.5	2.06	3.3
1936	193,000	91.9	36,200	42.0	41.8	1.96	3.1

The progressive decrease in nitrogen content is due to the additional raw sewage treated at the West Side Works, as more municipal sewers were connected to the interceptor, thereby increasing the ratio of fresh solids to the excess activated sludge which is pumped from the North Side Works to the Imhoff tanks at the West Side Works. In 1936, about 25 per cent of the production was used in agriculture. The remainder went to the dump. When stripping the sludge from the drying beds, loading to standard gage gondola cars is free. Otherwise loading from the storage pile is done by the taker. No charge is made for the sludge.

SURVEY BASED ON QUESTIONNAIRES

A complete survey of the disposal of sludge of all the municipalities in the United States was not made. However, data were obtained from the following states (Table XX) shown on page 884.

Utilization of Digested Sludge.—Four methods of using digested sludge are practised:

(1) Distributing the wet sludge from the digestion tanks to the fields (with a moisture content of around 85 to 95 per cent) and plowing it in.
(2) Hauling from the drying beds or the dump to the fields and spreading when the material has a moisture content ranging from 30 to 80 per cent.
(3) Heat drying, grinding, screening, and using on the soil directly (without admixture of chemicals) as commercial fertilizer is used.
(4) Heat drying, grinding, screening and mixing as a conditioner with chemicals in the preparation of mixed fertilizers.

Wet Digested Sludge.—Only two plants were found where wet digested sludge is directly applied to the soil, namely, Canton, Ohio, and Plainfield, New Jersey.

Hommon states (50) that at Canton, digested sludge from an Imhoff tank and trickling filter plant is used wet in fertilizing a city farm of

TABLE XX.—*Number of States and Municipalities Reporting on Sludge Use*

State	No. of Municipalities Reporting
Arizona	2
California	107
Colorado	4
Connecticut	10
Georgia	5
Illinois	12
Indiana	14
Iowa	30
Kansas	40
Kentucky	2
Maryland	4
Massachusetts	3
Michigan	11
Minnesota	23
Missouri	22
New Mexico	5
New York	20
New Jersey	18
North Carolina	6
Ohio	48
Oregon	10
Rhode Island	2
South Carolina	1
South Dakota	4
Texas	32
Virginia	3
Washington	2
West Virginia	2
Wisconsin	10
Total	452

550 acres. The results have been good with wheat, corn and oats. As a result of tests, sludge is pumped to adjacent farms within a two-mile radius. No revenue is received by the City for the service.

Downes (51) has grown oats and corn at Plainfield with wet sludge applied directly to a sandy soil. During the first year, 40 tons of spadable (75 per cent moisture) sludge was applied per acre, producing 42 bushels of oats. The second year, with 3 tons of sludge per acre, placed in hills only, 50 bushels of corn were raised per acre. Downes believes the land will take a coat of sludge every third year. The sludge is distributed by a 2 yd. manure spreader, hauled by a tractor. After a short drying period the sludge is turned under by a gang plow. Screenings are also plowed under.

Air-dried Digested Sludge.—A brief summary follows of the results of the canvass on the use of air-dried digested sludge from Imhoff tanks and separate digestion tanks, with or without trickling filters.

Orchards.—In various parts of the United States, air-dried digested sludge is reported as satisfactory in orchards for fruit trees, particularly around Rochester and Fairport, N. Y., and also for various berry

TABLE XXI.—*All Municipalities Reporting on Use of Sludge Exclusive of Activated Sludge*

State	Number	Use in Per Cent					No Data
		100	50–99	25–49	5–24	0	
		Pacific Coast States					
Arizona	2	1			1		
California	98	45	3	3	3	28	16
New Mexico	5	4			1		
Oregon	10						
Washington	2	2					
		Rocky Mountain States					
Colorado	4	2				1	1
Texas	26	6	1	1	3	13	2
		Middle West States					
Kansas	33	8	2	1	6	11	5
Iowa	29	12	3			7	7
Missouri	21	15				4	2
Illinois	11	5			4	1	1
South Dakota	4			1	1	1	1
Indiana	13	11		1		3	2
Kentucky	2	1			1		
Ohio	45	27	5	4	4	2	3
Minnesota	22	8	2	1	1	7	3
Michigan	11	5	1	1		4	
Wisconsin	9	3	2			3	1
		Atlantic Seaboard States					
Georgia	5	3	1			1	
Maryland	3	3					
Virginia	3	2		1			
North Carolina	4	3		1			
South Carolina	1	1					
West Virginia	2	2					
New Jersey	18	9	1	1		3	4
New York	19	9	2	1	1	2	4
Connecticut	7	2		2	2	1	
Massachusetts	3				2	1	
Summary:							
West of Rockies	117	52	3	3	5	28	16
Rocky Mountain	30	8	1	1	3	14	3
Middle West	200	95	17	9	17	43	25
Atlantic	65	34	4	6	5	8	8
Grand Total	412	189	25	19	30	93	52

bushes. Cary of Fairport reports the use of sludge every other year for six years on an orchard containing apples, pears, peaches, plums, cherries, and English walnuts. Ryan at Rochester reports that the first application is 5 tons per acre and thereafter 2 to 3 tons per acre on apple and peach orchards. The fertilization of citrus groves in

Southern California with air-dried digested activated sludge is discussed later on.

Trees.—Where trees are in a lawn, Lindquist of Rockford, Ill., suggests making holes with a bar to a depth of 1 to 2 feet, out a distance of a few feet from the tree to the extremity of its spread. He recommends applying heat-dried digested sludge at the rate of 15 lb. per 100 sq. ft. of tree spread.

Shrubs.—Many operators find that the digested sludge is used on shrubs. Lindquist of Rockford recommends fertilizing shrubs in the spring by mixing in the top soil 8 to 10 lb. of heat-dried digested sludge per 100 sq. ft. A later dressing of about 3 lb. per 100 sq. ft. may be applied.

Vegetables.—Reports from various states indicate a practical unanimity of opinion that digested sludge is worthwhile as a fertilizer for truck growers, particularly for crops of asparagus, sweet corn, tomatoes, cabbage, Swiss chard, spinach, lettuce, beans, melons, squash, cucumbers, carrots, potatoes, beets, turnips, parsnips and the like. Ryan at Rochester recommends its use for growing peas, but believes it unsuited for carrots, potatoes or turnips. Others do not recommend sludge for peas. In general, the sludge is applied like manure to the fallow ground and worked in prior to planting. At Rockford, Ill., Lindquist advises for root growths like potatoes mixing 1 lb. of superphosphate with 5 lb. of heat-dried digested sludge, and applying at the rate of 8 to 10 lb. of sludge to 100 sq. ft. of soil area.

Flowers.—Cary at Fairport, N. Y., states that at the sewage works the digested sludge worked well with asters, roses, sweet william, snapdragons, petunias and calendulas. Fair results were obtained on iris, cosmos, nasturtium, larkspur, balsam, pinks, phlox and Canterbury bells.

Lindquist at Rockford advises applying from 8 to 10 lb. of heat-dried sludge per 100 sq. ft. and working it well into the soil in the spring before planting. During the growing season, about 3 lb. per 100 sq. ft. may be worked in every 30 days.

Grass and Lawns.—Many observers recommend digested sludge for use on hay fields and lawns. However, the use of digested sludge on lawns around dwellings may produce odors for a week or two.

Lindquist of Rockford advises applying about 10 lb. of heat-dried sludge per 100 sq. ft. in the spring and later in the summer about 3 or 4 lb. per 100 sq. ft., when the grass shows signs of turning yellow. After applications, watering is desirable, followed later (when sufficiently drained) by rolling.

Use on Golf Course.—Air-dried digested sludge has been used for lawns in parks, on golf courses and private grounds. Ryan at Rochester indicates a method used on a new golf course. The sludge is composted in the ratio of 1 volume of air-dried sludge to 40 volumes of sand. After the compost has worked for three months, it is turned over and re-piled. The procedure may be repeated three or four times before use. Such a well rotted mixture was used as a base, to which was added

ammonium sulfate. Powdered limestone may be required to keep the mixture from developing acidity in the soil. At Winchester, Ind., digested sludge has been mixed with top soil in the proportion of 1 cu. yd. of sludge to 3 cu. yd. of top soil.

Quantities Applied.—The quantities of air-dried digested sludge applied to the soil vary greatly. On citrus orchards, Kellogg (52) recommends around 5 tons of digested activated sludge per acre. On grass in parks, from 10 to 20 cu. yd. per acre have been tried. For gardens, one operator mentions 20 to 60 cu. yd. per acre, another 25 to 50 tons per acre. In vineyards, around 15 cu. yd. per acre are used in California. Ryan states that around Rochester, from 2 to 3 tons of air-dried sludge are commonly applied per acre, although the first application may be as great as 5 tons per acre. At Schenectady from 20 to 40 cu. yd. are said to be used per acre. On grain, in California, 30 cu. yd. per acre are reported.

In a study of 15 sewage treatment plants in the United States (53), Wagenhals, Theriault and Hommon contacted local farmers using sludge extensively from the sewage works at Alliance, O., Canton, O., and Rochester, N. Y. (Irondequoit plant). At Alliance on clay soil, 10 loads per acre were applied. Increased yields were reported. Sludge from the Baltimore sewage works also increased yields on egg plants, cucumbers and grass. Canton farmers were enthusiastic over both liquid and air-dried sludge. Two farmers used 20 loads and a third used 15 loads of bed-dried sludge per acre for wheat. Another applied 8 loads per acre for winter wheat. Another used 20 loads per acre for oats. To two lots of 15 acres each, another farmer applied sludge to one and manure to another, obtaining superior grass on the sludged area. For hay fields, 15 loads per acre were recommended. For vegetables, one farmer applied 22 loads per acre. One reported good results on corn, tomatoes and orchards with 50 cu. yd. per acre.

At Baltimore, Keefer and Armeling report (54) the results of extended field experiments with digested sludge covering five years (1923–1927) on an area of 10 acres, divided into six equal sections of 1½ acres in turn divided into a number of equal plots on which different crops were planted. Comparisons were made of the following fertilizing materials.

	Weights Applied per Acre	
Section	1923–1924	1925–1926
1.	10 tons stable manure	10 tons stable manure
2.	1,000 lb. 5–8–5 commercial fertilizer	1,000 lb. 5–8–5 commercial fertilizer
3.	No treatment	
4.	1,000 lb. 2–8–2 commercial fertilizer and 20 tons dried sludge	1,000 lb. 5–8–5 commercial fertilizer and 40 tons dried sludge
5.	20 tons dried sludge	40 tons dried sludge
6.	40 tons liquid sludge	300 lb. 5–8–5 commercial fertilizer and 40 tons dried sludge

The per cent of nitrogen as ammonia in the sludge used during 1923–1926 was, on a dry basis:

Year	Section 4	Section 5	Section 6
1923	No analyses		
1924	2.56	2.56	3.19*
1925	2.06	2.25	1.84
1926	1.56	2.03	2.33

* Liquid sludge.

Keefer and Armeling concluded for Baltimore sludge:

1. Wet or air-dried sludge contributed fertilizing substances to the soil and increased the yield of the six crops planted (white potatoes, spinach, string beans, tomatoes, sugar corn and cabbage).

2. Air-dried sludge applied in amount of 20 tons per acre gave better results than did 40 tons of wet sludge per acre except when used to fertilize corn. This might be expected since, volume for volume, the former contained from three to five times more nitrogen as ammonia than wet sludge.

3. Spinach and tomatoes responded least to the use of air-dried sludge.

4. Of the six crops planted, white potatoes, cabbage and sugar corn throve best. The increase in yield of corn was particularly noticeable.

5. The results with corn and cabbage indicated that the sludge continued to give plant food to the soil during the second year after its application. No corresponding observations were made for the other four crops.

Schaetzle at Akron (55) found air-dried sludge valuable for many vegetables, when applied at the rate of 40 tons per acre, and plowed in.

Odors.—Well digested sludge is sometimes reported free from odors, even when used wet on grass. Some believe that grinding the cake will reduce odors to a minimum. However, the weight of opinion seems to be that air-dried digested sludge is better used where it can be promptly worked into the soil, rather than where it is exposed on the surface as on lawns, because odors are very likely to occur for a considerable period of time, particularly if the sludge has not been thoroughly digested.

Improvement of Condition.—Grinding the cake when removed from the drying beds improves its value. The sludge as removed is often hard to handle because of the fact that the cake is wet and sticky inside. Some claim grinding destroys the weed or tomato seeds.

Disintegrators of the Royer type are reported in use in the sewage works at Coney Island, Freeport, Garden City and Tonawanda, N. Y.; Stratford, Conn.; Dayton and Norwalk, O.; Durham, N. C.; Los Angeles, Calif., Reading, Pa.; and Battle Creek, Mich.

Increasing the Salability of Digested Sludge.—Daniels (56) notes that in most cases under his observation of some 300 plants in New Jersey, the sludge can not even be given away. He advances certain reasons for this state of affairs:

(1) The sludge is poorly digested.
(2) The sludge has a bad odor.
(3) Aesthetic dislike of source of product.
(4) Consumers lack knowledge of its value.
(5) Lack of initiative and salesmanship of plant operator.
(6) Condition of sludge, referring chiefly to lumpiness, which interferes with proper spreading.

He recommends grinding or disintegrating the sludge cake into relatively fine particles, all passing a ½-inch screen.

Daniels further advises mixing a fertilizer with air-dried sludge as a base. For grass and flowers he indicates:

Ingredients	Pounds
Ground sludge (dry basis)	360
Sand (filler)	100
Urea (commercial)	1
Acid phosphate (16 per cent P_2O_5)	50

In this mixture, the fertilizing elements are chiefly nitrogen and phosphoric acid. A bag containing 75 lb. (assuming sludge at 40 per cent moisture) should be sufficient for 150 sq. ft. of lawn, with two applications.

As a better balanced general fertilizer, Daniels also adds:

Ingredients	Pounds
Dried ground sludge	1,650
Ammonium sulfate	100
Acid phosphate (20 per cent P_2O_5)	200
Muriate of potash	50

Heat-drying of Digested Sludge for Market.—At the present time only two cities were found, namely, Rockford, Ill., and Dayton, Ohio, which are heat-drying and bagging air-dried digested sludge for the market (Table XXII). Two years ago, Grand Rapids was also heat-drying its sludge, but the machinery was damaged by fire in January, 1936, and has not been restored. For the period 1916 to 1923, Baltimore carried on heat-drying by contract (47, 48). The drying plant proved a financial failure, so the practice terminated in 1923. The air-dried sludge was sold to a reduction company on the basis that if the sludge when heat-dried contained 2 per cent nitrogen as equivalent ammonia on a 10 per cent moisture basis, the City received 81 cents per ton, weighed with the water content ranging from 10 to 15 per cent. One difficulty in meeting the required nitrogen content was the mineral

content which sometimes ran as high as 39.6 per cent because of sand. An average of all the analyses, from 1916 to 1920, showed water 15.81 per cent and nitrogen, on a dry basis, 1.86 per cent. In a run in 1916, the nitrogen content was found to decrease from 2.11 per cent to 2.08 per cent on a dry basis, in passing through the drier (47).

The nominal output is shown in Table XXII for the Dayton, Grand Rapids and Rockford Plants.

TABLE XXII.—*Heat-drying of Digested Sludge in U. S.*

Municipality	Began Production	Nominal Output Tons per Year
Dayton	1931	1,000–2,000
Grand Rapids *	1931	500–1,128
Rockford		250– 300

* At present rebuilding since fire of January 31, 1936.

Heat-drying has also been practiced (57, 58) at Plainfield, N. J., with a spray dryer, handling digested sludge, conditioned with alum.

Rumsey (59) at Grand Rapids called the product "Rapidgro." In 1933, he estimated the cost of grinding, pulverizing, drying, screening, bagging and weighing at $2.37 per ton. This cost increased 64 cents per ton in 1934 because of an increase in the price of the bags. The fertilizer sold for an average price of $10.00 per ton, packed in 110 lb. sacks. The tonnage of dry solids removed each year and sold as fertilizer were as follows:

Year	Tons Sold as Fertilizer	Tons Removed by Plant
1931–2	27	2,308
1932–3	522	1,898
1933–4	572	2,059
1934–5	1,128	2,591
1935–6	844	1,919

At Dayton, Tatlock (60) has been selling sludge since 1931. The air-dried sludge is dried in a rotary dryer, shredded, crushed, screened and bagged. The selling price per ton has ranged from $15 in 1930 to $6 in 1933, and is now around $10. The analysis of the sludge given on each bag is usually:

Ingredient	Per Cent Dry Weight
Nitrogen	2.4
Phosphoric acid	1.4
Potash	0.25

The application of from 200 to 400 lb. per acre is suggested by Tatlock.

The production of sludge at Dayton was as follows for each year on a dry basis:

Year	Tons Sold as Fertilizer	Tons Removed by Plant
1931	102	2,109
1932	1,082	1,751
1933	1,503	1,455
1934	1,187	1,332
1935	1,516	1,346
1936	1,243	1,090
1937	2,000*	2,139*

* Estimated.

At Rockford, Lindquist reports that the sludge is removed from the air drying beds with about 40 to 50 per cent moisture, when the weather permits, and is put through a hammermill, which operates directly over the dehydrator hopper. The sludge is then heat dried, using sludge gas and oil as fuel, and is packed in 80-lb. burlap bags.

A summary of the price schedules at Grand Rapids, Dayton and Rockford is given in Table XXIII.

TABLE XXIII.—*Heat-dried Digested Sludge Production and Selling Price, Dayton and Grand Rapids*

City	1930 1931	1931 1932	1932 1933	1933 1934	1934 1935	1935 1936	1936 1937	1937 1938
Dayton *		102	1,082	1,503	1,187	1,516	1,243	2,000 †
Grand Rapids		27	522	572	1,128	844	No production	

* Tonnage shown is for calendar year first above stated.
† Estimated.

Dayton

The price schedule has been:

100– 500 lb.	$ 1.00 per cwt.
500– 900 lb.	.85 per cwt.
1000–1400 lb.	.75 per cwt.
1500–1900 lb.	.65 per cwt.
1– 24 tons	11.00 per ton.
25 tons and up	6.50 per ton.

Grand Rapids—(Rebuilding since fire of January 31, 1936).

The price has always been:

Per 110 lb. bag at plant	$ .55
Per 110 lb. bag delivered within City	.65
Per 2200 lb., less than 5 long tons	10.00
Per 2200 lb., over 5 long tons	9.00

Rockford—The price schedule is:

Per 80 lb. bag at plant	$ .55
Per ton at plant	11.60
Per ton delivered within City	12.60
Per ton, over 5 tons in lot at plant	10.60
Per ton, over 5 tons in lot delivered within City	11.40

Economics of Sale of Heat-dried Digested Sludge.—Kraus (60a) has studied the question of disposal of the air-dried digested sludge at

Peoria. He concluded that the value of his sludge was not enough to warrant artificial drying.

Increasing Nitrogen Content.—The Rockford Sanitary District, Ill., appears to be the only municipality which increases the nitrogen in its sludge, prior to marketing, by adding chemical nitrogen. The sludge is digested in heated tanks, air-dried, shredded, heat-dried, enriched with sulphate of ammonia to bring the nitrogen up to 6.5 per cent, and 20 per cent super-phosphate to bring the phosphoric acid up to 2 per cent, then put through a hammermill and bagged. The mixture is sold by the carload for about $19.00 per ton, f.o.b. Rockford, as a 6–2 fertilizer. A recent fire destroyed the fertilizer warehouse and all of the mixing equipment.

Conversion of Sludge by Molds or Fungi.—Wigley (61, 62) developed a process at Atlantic City whereby moist sewage solids were said to be rendered inoffensive by molds, under conditions where light was excluded and temperature properly controlled (between 50 and 70° F.). Freshly settled sludge (not over 2 days old) was pumped onto air-drying beds, removed when sufficiently dry to handle, ground, further air-dried to bring down the moisture content to 30 per cent, and while still moist, stored in a dark building. Molds developed rapidly and in three or four days the sludge was said to be deodorized. The product sold for $20 a ton in ton lots. The analysis at Atlantic City, on a dry basis, was:

Ingredient	Per Cent
Nitrogen	1.96
Available nitrogen	0.76
Phosphoric acid	0.62
Potash	0.13
Organic material	35.9

This material has been used on lawns and flower beds.

Vacuum Filter Cake.—Green at Cedar Rapids, Iowa, reports that part of the digested sludge from the Cedar Rapids works is dried on sand beds to about 60 per cent moisture, with a nitrogen content around 3.5 per cent. The air-dried sludge is used by local golf courses after conditioning with super-phosphate and potash.

Lime Precipitation Sludge.—Prior to 1917 in Worcester, Mass. (when sludge pressing terminated), Lanphear reports that chemical precipitation sludge was in considerable demand. Much of the hauling was done in the winter, when the farmers had men and horses available. At the termination of sludge pressing, some motor trucks were used for hauling.

At Dearborn, Mich., lime precipitation sludge accumulated to December, 1934, when incineration began. Since that time the farmers have removed most of the storage pile. Some was taken for a golf course, but is said to have been difficult to handle. The Ford Motor Company is said to have used several thousand tons in preparing the ground for new lawns around its plant.

TABLE XXIV.—*Data on Sale of Sludge for Fertilizer Other than Activated Sludge*
(When Sold by the Ton)

City	1930 Population	Type of Plant	Per Cent Sold	Price Per Ton		
				As Is	Ground	Retail
Alabama						
Birmingham Co.				$0.50	$2.00	
California						
Brea	2,435	I.T.: T.F.		*1.08		
Fresno	52,513	Sep.Tk.		*0.50		
Huntington Beach	3,690	Sed.: Sep.Dig. T.F.	100	12.00		
Ojai	1,468	Sed.: Sep.Dig. T.F.		*0.85		
Oxnard	6,285	I.T.: T.F.	100	4.00		
San Bernardino	37,300	I.T.: T.F.	100	*2.00		
Illinois						
De Kalb San. Dist.	8,545	Sed.: Sep.Dig. T.F.	100	*0.50		
Indiana						
Huntington	13,420	I.T.		1.50		
Kentucky						
Fort Thomas	10,039	I.T. T.F.	100	2.00		
Michigan						
Battle Creek	43,573			*1.00	4.00	
Harbor Beach	1,892	I.T. S.F.	75	1.50		
Traverse City	12,539	Sed.: Sep.Dig.			B. 10.00	
Missouri						
Springfield	57,527	I.T. T.F.	50	*2.00		
New Jersey						
Atlantic City	66,198	Sed.			C.W. 15.00	W. $40.00
Audubon	8,904	I.T. T.F.		1.00		
Trenton	123,356	I.T.	10	0.75		
New York						
East Rochester	6,627	I.T. T.F.	50	$0.50		
Freeport	15,467				$10.00	
Ohio						
Akron	255,040	I.T.: T.F.	5	*0.25	5.00	$11.00
Findlay	19,363	Sed.: Sep.Dig.		*0.25		
Marion	31,084	I.T.: T.F.		1.50	‡10.00	
Norwalk	7,776	Sed.: Sep.Dig.	60		5.00	
Oberlin	4,292	Sed.: Sep.Dig.	100	*0.50		
Toledo	290,718	Sed.: Sep.Dig.	15	*1.00	6.50	
Pennsylvania						
Elizabethtown	3,940	I.T. T.F.	100	1.00		
Wisconsin						
Madison	57,899	I.T. T.F.	80	*1.00	†6.00	
Monroe	5,013	Sep.Tk. S.F.	100	0.25		

* Price per cubic yard.
B. Additional charge made for bags.
W. Wigley mold cured.
† Sacked.
‡ Includes local delivery.
C. Price to jobber.

NOTE: Abbreviations used are:

I.T. = Imhoff Tank.
Sed. = Sedimentation.
Sep. Dig. = Separate Digestion.
Sep. Tk. = Septic Tank.
S.F. = Sand Filter.
T.F. = Trickling Filter.

Phillipsburg, N. J., reports lime sludge is taken by farmers and used on corn, potatoes, fruit and truck, but a decreased use was reported in 1937. At Winston-Salem, N. C., lime sludge has been used largely for fill, though some use has been made on land. Many North Carolina soils are said to require a lime treatment.

Sale of Digested Sludge.—From the questionnaires sent out by the Committee, all the data received on the sale of digested sludge are listed in Table XXIV and XXV. These prices vary considerably, for sludge as removed from the drying bed ranging from $0.25 to $2.00 per cubic yard and from $0.25 to $12.00 per ton, according to the basis of

TABLE XXV.—*Data on Sale of Sludge for Fertilizer Other than Activated Sludge*
(When Sold by the Bed or the Load or the Year)

City	1930 Population	Type of Plant	Per Cent Sold	Price Per Bed	Price Per Load	Year
California						
Gilroy	3,502	Sed.: Sep.Dig.				$100.00
Riverside	29,696	Sep.Tk.	100		$2.00	
Seal Beach	1,156	I.T.		$20.00		
Whittier	14,822	I.T. T.F.	100	25.00		
Illinois						
Downers Grove San. Dist.	8,977	I.T.: T.F.	100		1.00	
Indiana						
Brazil	8,744		100		0.50	
Michigan						
Pontiac	64,928	I.T. T.F.	25		0.50	
New York						
Middletown	21,276	Sed.: Sep.Dig.	25		1.00	
Rochester	328,132	I.T. T.F.	95		0.25	
Schenectady	95,692	I.T. T.F.	100		0.25–0.75	
Ohio						
Columbiana	2,484	I.T. T.F.	100		1.00	
Norwalk	7,776	Sed.: Sep.Dig. T.F.		5.00*		
Texas						
El Paso	102,421	Sed.	100		0.50	

* About 10 cu. yd.

TABLE XXVI.—*Data on Sale of Sludge for Fertilizer Other than Activated Sludge, Heat-dried*

	1930 Population	Type of Plant	Per Cent Sold	Price		
				Per Bag	Per Ton	
					Retail	Wholesale
Dayton, Ohio	200,982	Im.Tk.	70	$1.00	$11.00	$6.50
Grand Rapids, Mich.	168,592	Sed.: Sep.Dig.	50			
Plainfield, N. J.	49,330	Sed.: Sep.Dig. T.F.	100		10.00	
Rockford, Ill.	85,864	Sed.: Sep.Dig.	30		11.60	

sale. When ground, the prices range from $2.00 to $10.00 per ton. Specially processed sludge sold at $15.00 per ton.

The data on heat-dried digested sludge are summarized in Table XXVI.

This summary indicates that relatively few sewage works now sell digested sludge other than activated. The majority give their sludge away.

Utilization of Activated Sludge

Because of its greater nitrogen content, heat-dried activated sludge has had much more development as a fertilizer than digested sludge. At the outset of the activated sludge development in the United States, such pioneers as Hatton, Bartow and Sands realized the importance of developing a useful by-product, the sale of which would reduce the cost of operating the process. Among the early investigators of the fertilizer values of activated sludge were Hatfield and Noer. In 1923, the Milwaukee Sewerage Commission enlisted the active support of the Wisconsin Agricultural Experiment Station. The investigation was placed in the hands of A. J. Noer, an agricultural specialist, under the direction of Professor E. Truog. Nearly four years of intensive research followed in the laboratory, greenhouse and field.

Long before Milwaukee began production of activated sludge in 1926, extended tests were conducted with the aid of activated sludge produced by The Sanitary District of Chicago in its Des Plaines River works (in operation in 1922), on more than 100 plots at the various experimental farms of the Wisconsin Agricultural Experiment Station and on fairways and greens in four country clubs in Milwaukee. As an example of thorough preparation, the details of the tests are of interest, together with pertinent notes from the Illinois Water Survey investigations.

Noer has compiled (63) some of the earlier analyses of the sludges from Milwaukee, Houston, Des Plaines (The Sanitary District of Chicago) and Pasadena.

Early Analyses of Activated Sludge, Per Cent of Dry Solids

	Milwaukee	Houston	Des Plaines	Pasadena
Total N	6.37	4.84	4.72	6.41
Water-soluble N	0.49	0.84	0.72	2.61
Water-insoluble N	5.88	4.00	4.00	3.80
Total phosphoric acid	2.99	2.33[1]	4.20	3.94

Bartow and Hatfield (64) studied some of the properties of dried activated sludge when used as a fertilizer. They reported that dried activated sludge contained only spore-forming bacteria. They stated that a grease content up to 11 per cent did not injure the fertilizing value. They concluded that the nitrogen in activated sludge was readily available. By making pot tests with wheat, they found the pots

fertilized with sludge gave the best results, both in rapid growth and yield per acre.

Noer made pot tests with Milwaukee activated sludge and other materials, which indicated (63) that the quality of nitrogen in activated sludge compares favorably with the common organic fertilizer materials. Some of Noer's data are given in Table XXVII.

Field Tests.—Kadish noted (65) the results on ten field tests with various mixtures, which included, as the source of nitrogen, comparable amounts of activated sludge, ammonium sulfate, sodium nitrate and tankage. Growing tests were made in various localities in Wisconsin to establish the relative value of the mixtures on sweet corn, cabbage, potatoes, tomatoes, cucumbers, beans, tobacco, sugar beets, onions, peppers, egg plant, squash, pumpkins, small grains and barley.

TABLE XXVII.—*Percentage of Nitrogen in Activated Sludge and Other Nitrogen Carriers Made Available and Taken up by Oats During 65 Days' Growth in Quartz Sand Cultures*

Source of Nitrogen	Total Nitrogen in Fertilizer Material	Amount of Added Nitrogen Taken up by Crop
	Per Cent	Per Cent
Activated sludge	4.95	39.1
Fertilizer tankage, low grade	4.64	37.9
Fertilizer tankage, high grade	8.26	32.3
Feeding tankage	9.70	48.9
Dried blood	10.71	46.2
Hoof meal	13.02	52.0
Digested leather	8.24	23.1
Cottonseed meal (1)	6.51	44.4
Cottonseed meal (2)	7.30	39.2
Garbage tankage (1)	1.72	5.8
Garbage tankage (2)	2.62	0.4

On cabbage, activated sludge even when used as the sole source of nitrogen, proved to be as good a source of nitrogen as any used.

On sweet corn, activated sludge compared very favorably with sulfate of ammonia and tankage as the sole source of nitrogen.

"Activated sludge as the sole source of nitrogen proved very effective on such crops as sweet corn, cucumbers, beans, pumpkins, etc., but on tomatoes, tobacco, potatoes, etc., mixtures containing both organic and inorganic nitrogen were best. Probably such a combination will always prove best in mixed fertilizers. The organic nitrogen carriers, because of their colloidal nature and absorption capacity, exert a favorable effect on the mechanical condition of the mixture and their use also results in a minimum loss of nitrogen, because it is made available as needed by the plant."

The Wisconsin Experiment Station reports (66) that in trial plots in the field,

"in crops with a short growing season, such as cauliflower, early cabbage and tobacco, the most satisfactory results were obtained with a mixture wherein one-third of the nitrogen came from each source: sludge, sulfate of ammonia and nitrate of soda. Crops with a longer growing season, such as corn, potatoes and onions, were able to utilize mixtures containing larger proportions of sludge."

Fertilizer Value of Activated Sludge

In plot experiments at the Wisconsin Experiment Station, activated sludge proved (25) a better source of nitrogen than digested leather and it was about equal to tankage, cotton-seed meal and dried blood.

Sludge tests compared favorably with tankage and sulfate of ammonia as the sole source of nitrogen on such crops as sweet corn, cucumbers and pumpkins, but on tomatoes, tobacco and other crops, the mixtures containing organic nitrogen always proved the best method of supplying nitrogen in mixed fertilizers.

Carnations.—Sykora (32) described trials of activated sludge in commercial growing of carnations. The usual commercial mix has been 1–8–3 or 2–12–4. The results were gratifying. Noer (25) states that with activated sludge and phosphate, from 10 to 30 per cent increase in blooms was secured.

Roses.—Sykora described (32) the use of activated sludge on roses. Usually the commercial mix is a 5–8–7. The results were gratifying. Noer states that in a Milwaukee greenhouse, 686 additional blooms were obtained per 1,000 sq. ft. of bench area.

Texas Experiments.—Reynolds described (67) tests at the Texas Agricultural Experiment Station utilizing Houstson sludge in amounts from 500 to 2,000 lb. per acre. This sludge contained 4.6 per cent nitrogen and 2 per cent phosphoric acid (as P_2O_5). In growing cotton at the College Station, an increase of 37 to 47 lb. of lint per acre was obtained, and at Angleton, an increase of 16.4 per cent, or 32 lb. per acre. In growing corn, the yield increased 13.9 per cent.

Turnips.—McVea reports (68) at Houston a large increase in the weight of turnips produced when sludge was used as fertilizer.

Use on Garden Crops.—Very briefly, the use of activated sludge as a fertilizer on garden crops has been effective as reported in the following:

Barley (74)
Cabbage (25, 54, 70, 71)
Corn (25, 37, 54, 63, 67, 69, 71)
Lettuce (37, 70)
Potatoes (25, 54, 63, 69, 74)
Radishes (37)
Small grains (69)
Spinach (54)
String beans (54)
Tomatoes (37, 54, 70, 71, 72)
Tobacco (69, 70, 71, 72)
Vegetables (37, 69, 70, 71, 72)

Grass.—The investigations of the Milwaukee Sewerage Commission (73) and others (74) early pointed to the value of heat-dried activated sludge as a fertilizer for grass, whether on lawns or on fairways and greens on a golf course. Unlike many chemical forms of nitrogen, ac-

tivated sludge will not burn grass, and it has a residual nitrogen value which is not found in nitrate of soda or other quick acting chemicals. Heat-dried activated sludge is also free from weed seeds.

For lawns, an application varying from 3 to 5 lb. per 100 sq. ft. is recommended on an average.

Golf Courses.—Noer believes (75) that on established fairways, the main dependence must be put on nitrogen, with phosphorus and potash playing minor roles. The fertilizers which are least likely to injure turf contain the smallest amounts of water-soluble nitrogen. A mixture, or organic and water-soluble nitrogen is being used in many cases. The quick-acting nitrogen promotes rapid initial growth and the slower-acting organic nitrogen subsequently feeds the turf.

Cotton.—In South Carolina, Paden (76) describes field tests from 1928 to 1935 on growing cotton, with 78 plots, each 1/400 acre, comparing 19 different carriers of nitrogen, including Milorganite. The effect of lime was also studied. The greatest response from the use of lime was secured with Milorganite, equivalent to 24.6. On total production of seed cotton per acre per year, Milorganite showed 1,792 lb. as against an average of 1,933 lb. and a maximum of 2,200 lb. on unlimed soil, and 2,233 lb. as against an average of 2,080 lb. and a maximum of 2,335 lb. on limed soil.

The Need of Organic Nitrogen Carriers

"Organic nitrogen carriers (77), because of their favorable effect on the mechanical condition of the fertilizer mixture and also because their use results in a minimum loss of nitrogen by leaching, as the nitrogen becomes available as required by the growing plant, will probably always have a certain advantage over inorganic forms, and will probably always be used to supply a portion of the nitrogen in mixed goods. The inorganic forms of nitrogen are, in the main, more readily available, but are easily lost by leaching and do not help to improve conditions for desirable bacterial activity, as is done by the organic forms. Undoubtedly, a mixture of inorganic and organic nitrogen, which combines the desirable properties of both forms, will always prove to be the best method of supplying the nitrogen mixed fertilizer for general use. Some of the organic nitrogen carriers previously used by the fertilizer manufacturer are now being diverted into stock feeds, while the supply of others has become partly exhausted, or has not kept pace with the growing demand. There is thus a growing shortage of organic fertilizer materials. Activated sludge, because of its good qualities as an organic nitrogen carrier and fertilizer conditioner, is ideally adapted to fill this shortage."

This opinion on the value of organic nitrogen in a mixed fertilizer was confirmed recently by the Tobacco Research Committee, which recommended (78) for the 1938 tobacco crop in the Southern States a mixed fertilizer in which one-third of the nitrogen should be derived from high-grade organic materials of plant or animal origin, one-third from materials supplying nitrogen in the nitrate form, and one-third from urea or standard inorganic sources of nitrogen. The general recommendation is that not less than one-third of the total nitrogen should be in organic form, and not less than one-fourth of the nitrogen should be water-insoluble.

Dewatering of Activated Sludge

At the present time, it is estimated there are over 122 sewage treatment works in the United States utilizing the activated sludge process. Of these, 117 employ sludge digestion followed by air-drying beds, and four (Chicago, Houston, Milwaukee, Pasadena) are using dewatering with vacuum filters and heat-drying (Table XXVIII). One plant (San Marcos) disposes of its excess sludge direct on land.

Table XXVIII.—*Municipalities Which Heat-dry Activated Sludge*

Municipality	Began Production	Present Nominal Output, Tons per 24 Hrs.
The Sanitary District of Chicago—		
New Calumet Works	1936	30
Houston *	1932	12½
Milwaukee	1926	120
Pasadena *	Sept. 1, 1928	10

* Operated prior to date noted for tuning up or experimental purposes.

Indianapolis operated for a few months in 1931 in an experimental way, manufacturing about 514 tons of dried sludge, all of which was marketed. None has been dried since.

The production of heat-dried activated sludge in the United States by Houston, Milwaukee, Pasadena and Indianapolis is shown in Table XXIX. The data on the sales of heat-dried activated sludge are compiled in Table XXX. All the Houston sludge and the major portion of the Milwaukee sludge are sold on a basis of the current price of the organic nitrogen and phosphoric acid content.

Table XXIX.—*Quantity of Heat-dried Activated Sludge Sold, Tons of 2,000 Pounds*

Year	Houston	Milwaukee	Pasadena	Indianapolis	Total
1926					
1927		20,258			20,258
1928		30,866	839		31,705
1929		31,602	2,533		34,135
1930		29,311	3,352		32,663
1931		26,344	3,385	514*	30,243
1932	2,010	37,395	3,892		43,297
1933	1,992	34,818	3,266		40,076
1934	2,083	32,088	2,630		36,801
1935	2,004	31,523	3,546		37,073
1936	1,921	46,726	3,304		51,951

* Experimental—one year only.

Digested Activated Sludge

Very little has been written about the disposal of air-dried digested activated sludge, except in Southern California. Such sludge has been used there and in Phoenix, Arizona, on citrus orchards. At San An-

TABLE XXX.—*Data on Sale of Activated Sludge, Heat-dried, for Fertilizer*

City	1930 Population	Per Cent Sold	Price Per Ton Wholesale		Remarks
			Bulk	Bagged	
California					
Alhambra	29,500	100			These four towns
Pasadena	123,000	100		$30.00	are served by a
South Pasadena	13,724	100			common plant
San Marino	4,500				
Indiana					
Indianapolis		†Exptl.		15.00	
Texas					
Houston	292,352	60	‡		
Wisconsin					
Milwaukee					
Metro. Dist.	698,550*	100	$17.00§		

NOTE: Pasadena operates a plant jointly for Alhambra, Pasadena, South Pasadena, and San Marino.

* Population estimated at 740,986 for 1935. Actually contributing 699,298.

† Experimental in 1931; sold 514 tons.

‡ Price is based on current price of organic nitrogen and phosphoric acid content.

§ F.O.B. city noted. Average for first seven months 1937.

tonio, Texas, air-dried digested sludge, partly activated sludge, is reported used at the rate of 5 tons per acre.

Orchards.—In the use of digested sludge in citrus orchards, the most highly organized distribution is in Southern California. The sludge digested is a mixture of fresh and activated. According to H. C. Kellogg (52), the use of sewage sludge in a major way as a fertilizer in California dates from about 1926, when he began to purchase the sludge wholesale directly from sewage treatment plants, and distribute it to farmers. At present, some 10,000 tons annually are handled, including the entire sludge output of Pomona, Whittier, Brea, San Bernardino, Seal Beach and the Los Angeles County Sanitation Districts (a total population of over 271,000, as of 1930).

The necessity of adequate preparation by thorough air drying and grinding was early recognized. Further, by handling a large quantity, suitable equipment for delivery and spreading was developed.

At first, the sludge was ground and sacked in 100-lb. bags. This proved uneconomical and became a general nuisance because of the accumulation on the premises in order to dry it. The customers would not pay the additional cost of grinding, sacking and handling. Further, the accumulated sludge deteriorated in piles by heating, causing loss of ammonia.

The method finally developed and now in use is to dry the sludge on the beds to a moisture content between 5 and 30 per cent, if possible. Drying is aided by forking repeatedly. The cake is then removed, ground to pass a one-inch mesh screen, loaded into box-bodied trucks, carrying from 5 to 10 tons per load and delivered to the grove at the

roadside. It is picked up by small, one-ton trucks built unusually light, and spread around the drip of the trees, in amount varying according to their size and age. It is then disked into the soil to a depth of approximately 4 to 6 inches.

Sludge sells in bulk, under the brand of "Sludgeon," at an average price of $7 per ton at the roadside, with an added charge of 50 cents per ton for spreading in the orchard. The average analysis quoted at the time of sale is:

Nitrogen	2 to 2.5 per cent
Phosphoric acid	1 to 1.5 per cent
Potash	0.5 to 1 per cent
Organic matter	40 to 50 per cent

Adjustments of cost are made according to the actual delivery. The average grove uses around 3 to 5 tons per acre.

Sludge has been used extensively as a fertilizer for citrus orchards in Orange and Los Angeles Counties in Southern California. Several orange groves which depend completely upon sludge as a source of plant food are said to be in excellent condition, producing large high-grade fruit. Some groves apply a commercial fertilizer in addition, with satisfactory results. The success of the sludge as a fertilizer is evidenced by its use year after year by the same growers.

The soil of Southern California is sandy and granular, needing humus. For these conditions, sewage sludge seems specifically fitted. With a low normal annual rainfall (15 inches), the air drying of sludge can reduce the moisture content to a very low figure. With the population available in the vicinity of the orchards, the scheme seems a very happy solution of the local sludge disposal program.

Disposal of Filter Cake.—At Charlotte, N. C. (79), there are two activated sludge plants, each of 6 m.g.d. capacity, one equipped with digestion tanks and sludge drying beds, the other with an Oliver filter. The filter cake is disposed of by spreading on land and plowing under. The majority of the output is taken by neighboring farmers.

Enrichment of Air-dried Sludge.—The air-dried digested activated sludge at Charlotte, N. C., is removed (79) from the drying beds by a private concern, which processes it into a marketable product by building up its fertilizing value by adding nitrogen, potash and phosphate. The product is marketed under the names of "Humite" and "Turfood." The City receives from $0.75 to $2.00 per ton for the sludge, on a sliding scale, depending on the amount removed each month. The contract was for a period of 10 years. The City provides and maintains the drying beds.

Sale of Digested Activated Sludge.—Excepting the sale of digested activated sludge in the Los Angeles territory, the data from the municipalities reporting on sales are listed in Table XXXI. The prices vary considerably. The California prices seem to be higher than those east of the Rocky Mountains.

Land Disposal of Activated Sludge.—At San Marcos, Texas (80), the excess sludge from a small activated sludge plant serving about

TABLE XXXI.—*Data on Sale of Digested Activated Sludge for Fertilizer*
(Other than Heat Dried)

City	1930 Population	Type of Plant	Per Cent Sold	Price Per Ton		Price Per Bed	Price Per Cu. Yd.
				As Is	Ground		
Arizona							
Phoenix				$0.50			
California							
Escondida	2,000						$1.89
Lodi	6,750			1.00			
Los Angeles Co.							
San. Dist.	200,000		100	*2.00			
Pomona	20,804	I.T.: A.S.	100	5.00			
Indiana							
Richmond	32,498		100				1.00
Kansas							
Ottawa	9,563	A.S.: Dig.		1.00			
Michigan							
Muskegon Heights	15,584		100				1.00
Missouri							
Moberly	13,772	A.S.: Dig.	60	1.50			
New Jersey						†$1.00	
Collingwood	12,723	A.S.: Dig.				‡ 2.50	
North Carolina							
Charlotte	82,675		40				
Durham	52,937	Sed.: A.S.		§1.25			
Ohio							
Elyria	25,633	A.S.	100			5.00	0.50
Texas							
Waco	52,848	A.S.				*50.00	

* Price changed to $1.40 per mg. sewage treated about 1935.
† Per load: purchaser loads from bed.
‡ Per load delivered.
§ Per ton of dry solids. Buyer loads on conveyor belt.
‖ Per year for output.

6,000 persons has been disposed of over a period of years on 6 acres of sandy soil. The land is plowed in furrows and the sludge is discharged into successive sets of furrows on successive days. When a group of furrows has been used for one day, it is allowed to dry. The surface crust is then broken down by a single plowing on the center of the furrow and the land is again ready for use.

ESTIMATED USE OF SLUDGE AS FERTILIZER IN UNITED STATES

A recent estimate by the Division of Fertilizer Investigations, Bureau of Chemistry and Soils of the U. S. Department of Agriculture, presents the following tentative figures on the use of sludge as fertilizer in the United States, separating heat-dried activated sludge, air-dried or undried activated sludge, and other sludge comprising undigested, digested, Imhoff and septic tank sludge and screenings:

TONS OF SLUDGE USED FOR FERTILIZER IN THE UNITED STATES

Year	Activated Sludge		Other Sludge
	Heat-dried	Air-dried	
1925	1,000*		200,000
1930			300,000
1936	52,000	10,000	400,000

* Estimated by the Committee.

Commercial Brands for Sludge Fertilizer.—Considerable ingenuity has been exercised in coining catchy names for sludge products. Milwaukee started the idea by offering a prize of $100 for the best name, thus securing the compounded trade name of "Milorganite," a shortened version of Milwaukee organic nitrogen. Other names are noted in Table XXXII.

TABLE XXXII.—*Names of Commercial Brands of Sludge Sold as Fertilizer*

Locality	Brand
Akron, Ohio	Akra-Soilite
Charlotte, N. C.	Humite; also Turfood
Grand Rapids, Mich.	Rapidgro
Houston, Texas	Hu-Actinite
Indianapolis, Ind.	Indas
Madison, Wisc.	Nitrohumus
Marion, Ohio	Humusite
Milwaukee, Wisc.	Milorganite
Pasadena, Calif.	Nitroganic
Southern California	Sludgeon

State Laws.—In general, the sale of sludge as a raw material is allowable in all states. However, if sludge is mixed with other fertilizer material, some states then require that the final mixture contain a minimum of 14 to 16 units of plant food (Ohio, New York and others).

HYGIENIC ASPECTS

Wolman summarized (81) the hygienic aspects of the use of sewage sludge as fertilizer prior to 1924 for both foreign and American practice. On the farms around Paris, the use of sewage or sludge was forbidden where vegetables or fruits are produced which are to be eaten raw. In England, the practice was that sewage in any form should not come in contact with growing crops that may be consumed without cooking. In the United States, at that time only three states had regulations. In addition, Michigan advised against the use of sludge for fertilizing vegetables.

Obviously, the index of the danger of using wet sludge or air-dried sludge for the growth of crops must lie in the evidence of experiments

to determine the life of pathogenic organisms contained therein and of experience where such material is used.

Wolman points out (81) that a comprehensive list of experiments prior to 1924 indicated that Bacterium typhosum had been recovered in varying forms of human sewage in anywhere from 6 hours to 365 days and in various characters of soil in anywhere from several to 540 days. However, all the studies indicating a survival of over one week were made prior to 1912. Most of the determinations were made prior to 1904. More recent tests made in 1923 in the laboratory of the Maryland State Board of Health indicate that in a sewage sludge free to undergo normal digestion, the survival of typhoid fever bacilli is probably less than 7 days. This finding is supported by other independent investigators of recent date, such as Kligler, who in 1921 (82) concluded that Bacterium typhosum may survive five days and that in dry or acid (moist or dry) soils most pathogenic bacteria will die within ten days. Courmont and Rochaix in 1922 concluded that the typhoid-paratyphoid group disappears in 2 or 3 days in aerated or non-aerated sewage, but may live much longer in sterilized sewage.

Wolman concludes that the laboratory evidence would indicate that sewage sludge held in a digestion tank for at least 10 days could be applied to the soil for fertilizing purposes without detriment to the public health, through the dissemination of vegetable-borne diseases. Wolman recommended (81, 83) that all sludge be given at least ten days' digestion, and be used only on the ground before the crops are planted and not sprinkled over or brought in direct contact with growing vegetables.

The report on a test made at Michigan State College on sludge from Grand Rapids concluded (84):

> "The marked reduction of Esch. coli and Aer. aerogenes in Rapidgro as compared to wet sludge and ground air dry sludge indicates that gram negative pathogens, as, for example, the typhoid bacillus, must also be decidedly reduced. In fact, it is a very safe conclusion that such pathogens have disappeared entirely. The absence of streptococci and staphylococci is further evidence of the absence of pathogenic bacteria."

In a few tests at Rockford (84) in 1934 it was found that there was a marked reduction of B. coli in the fertilizer as compared with the raw or digested sludge and the air dried cake. It was concluded that there are probably very few if any pathogenic bacteria in the fertilizer.

Heukelekian and Schulhoff (85) conducted two experiments of the effect of digestion on Bact. typhosum. In each case raw sewage solids were seeded with digested sludge. The mixtures were then artificially inoculated with Bact. typhosum cultures grown on agar slants. The mixtures were then incubated at 20° C., and samples taken at intervals for the determination of Bact. typhosum. The results were as follows:

BACT. TYPHOSUM PER C.C. AFTER DAYS NOTED

Days:	0	1	2	3
I	220,000	23,000	3,000	1,000
II	30,000	1,000	No recovery	No recovery

Heukelekian and Schulhoff concluded that a very rapid reduction in the numbers of Bact. typhosum took place during the first few days of the digestion of fresh solids.

Tanner (86) brought up to date in 1935 the public health significance of sewage sludge when used as a fertilizer and pointed out that literature cites cases where fresh vegetables raised on polluted soil may transmit pathogenic bacteria. Most of the data cited on the longevity of Bacterium typhosum in soil are old, prior to 1919, and relate largely to night soil or tests of cultures in soil.

Ruchhoft, in the most extensive investigation yet reported on this subject (87), recently isolated Bacterium typhosum from activated sludge and found a survival in aerated sludge after 8 to 14 days. He concluded that "wet activated sludge cannot be considered innocuous. At times it may be quite infectious. Caution should be observed when it is used as a fertilizer for truck gardens."

Tanner concluded (86) that "the application of sewage sludge to soil on which vegetables which may be eaten raw are grown should be practiced with caution. While results of longevity studies on pathogenic bacteria in sludge would probably be greatly influenced by the nature of the sludge and the conditions under which it is stored and handled, sufficient data have been recorded to indicate the presence of viable Bacterium typhosum cells in sludge. At best, the sludge should be added to the soil in the late fall, winter or early spring. Wolman's advise is probably sound—that it should not be added to growing crops."

However, Ruchhoft added (87) "sludge for fertilizer is usually obtained after filtering and drying activated sludge and after drying Imhoff sludge on sand beds. It is well known, however, that drying alone immediately reduces the number of viable Bact. typhosum by a large percentage." Unfortunately, time did not permit Ruchhoft to study such dried sludges.

State Regulations.—California, alone, out of 33 states reporting to the Committee, has adopted regulations under its Public Health Act (88), whereby the disposal of sewage, sewage effluent or sludge for irrigation or fertilizing purposes requires a permit therefor issued by the State Board of Health to the municipality, district, firm or person owning or operating the sewer system. Users of the sewage, effluent or sludge are, however, liable as agents for the violation of such permit.

In general, the California rules cover the following ground:

Raw sewage containing human excrement shall not be used for irrigating growing crops.

Raw or undigested sludge shall not be used for fertilizing growing vegetables, garden truck or low growing fruit or berries unless the sludge has been kiln-dried, bed-dried or aged in storage for at least 30 days, well digested (*i.e.*, odorless, readily drainable and containing not over 50 per cent of the total solid matter in volatile form), or conditioned to the satisfaction of the State Board of Health.

Settled or undisinfected sewage effluents are banned for growing vegetables, garden truck, berries or low growing fruit, or for watering vineyards or orchards where windfalls or fruit lie on the ground. Such liquid may be used for watering nursery stock, cotton,

field crops such as hay, grain, rice, alfalfa, fodder corn, cow beets and fodder carrots, provided no milch cows are pastured on the land, when moist with sewage, or have access to ditches carrying sewage. Use is also permitted for growing vegetables used exclusively for seed purposes.

Well oxidized effluents highly disinfected or otherwise treated for bacterial removal have a less restricted use. However, many state sanitary engineers give cautionary advice to those who request instructions as to the use of sewage sludge. Such comments may vary in degree. Only Oklahoma appears to prohibit the use of sludge.

In 1924, Wolman stated (81) that 36 states had not formulated any regulations. Washington prohibited the use of the contents of privies, cess pools or other receptacles for human excrement. Montana prohibited the sale of sewage irrigated vegetables. California had a circular stating the regulations of the State Board of Health. Apparenty in 1937 California was still the only state with regulations. Eleven states advise caution in use or use for forage crops only.

From an inquiry of the various state sanitary engineers, the Committee learned that at present (1937):

Colorado indicates that sludge may be used if air-dried in the sun to 10 per cent moisture content.

Iowa urges caution, particularly in the use of sludge on garden products.

Indiana advises against the use of green sludge on vegetable crops.

Florida, Illinois, Massachusetts, Minnesota, New Jersey and Wisconsin indicate the use is inadvisable on crops (vegetables or fruits) eaten uncooked.

Virginia cautions against use except on crops such as corn or vegetables which grow an adequate distance above the ground surface, to avoid danger of contamination.

Kentucky, New Mexico and Tennessee advise the use solely on field crops such as corn or cotton.

Michigan advises the use only on crops eaten by animals.

Oklahoma informs inquirers that it is not permissible to use sludge for fertilizing truck gardens.

Texas does not permit the use of sewage or effluent on vegetables eaten raw.

Warning on Use.—In distributing digested sludge, a number of towns issue a circular to each user warning against indiscriminate use. Cohn uses the following at Schenectady.

"Sludge fertilizer is produced by the treatment of municipal sewage. For this reason, care should be taken in its use.

"Keep sludge from all crops that grow in or on the ground and go to the table uncooked."

Similar advice is given by Freeport, L. I., and Findlay, Ohio.

Warrick stated (89) that he knew of no serious infection or illness in Wisconsin resulting from the use of sewage sludge as a fertilizer for garden or field crops. He believed that a heat-dried activated sludge can be used as a fertilizer without danger from the public health viewpoint. In his opinion, digested sludge could be used with little or no hazard, except possibly as regards raising vegetables eaten raw or uncooked, but he advised the distributor to notify the user that such sludge is not recommended for crops to be eaten raw.

Dugan of Kentucky believed (89) sludge is suitable for field crops.

Weston of Massachusetts recommends proper preparation. Otherwise, digested sludge should not be used on vegetables eaten raw.

Calvert points out that no green sludge should be used on vegetables. He further states that no sickness resulted from the use of 117,000 cu. yd. of Indianapolis activated sludge after long storage in sludge lagoons.

Fox of New Mexico advises that sludge should be well digested and recommends that its use be restricted to forage crops.

Howe of Colorado believes in thorough drying, preferably in the sun.

Leonard of Idaho believes in prohibiting the use of sludge on garden crops, particularly on vegetables used raw.

Conclusions

1. Sewage sludge is of use as a fertilizer, if properly prepared and applied. Its value varies with the type.

2. Fresh sludge is seldom used and may be troublesome, because of grease content, odors and bacteria.

3. Digested sludge, whether wet, air-dried or heat-dried, appears to have use as a substitute for manure and is of about the same fertilizing value. In its wet form it must be used relatively close to the sewage works. In its air-dried form it may be worth while to transport it a short distance, perhaps 20 miles. In its heat-dried form with a sufficient nitrogen content, it may justify a considerable haul. The nitrogen content however is relatively low (0.5 to 3 per cent, dry basis) as compared with heat-dried activated sludge (3 to 6 per cent, dry basis).

4. Activated sludge, heat-dried, appears to have real value as a source of organic nitrogen fertilizer, whether used directly or in mixture. It is free from weed seeds, blends quickly with the soil, when applied has a slight odor for a very short period, and can be used with safety in fertilizing practically all crops requiring nitrogen in organic form.

5. The sewage works offering digested sludge are scattered all over the United States. The air-dried sludge is most commonly used locally within an easy distance of truck haul. Most of the works give away this sludge. Many load it free of charge.

6. Air-dried digested sludge should preferably be disintegrated or ground to remove lumps before distributing for use. When so prepared a charge is usually made in addition to a charge for bags.

7. Both wet and air-dried digested sludge should be handled like manure and plowed under as soon as practicable after distribution.

8. Heat-dried digested sludge was prepared in 1937 at only three plants, Dayton, O., Rockford, Ill., and Plainfield, N. J. Years ago at Baltimore a contractor abandoned heat-drying of air-dried digested sludge because it was financially unsuccessful. Fire has also temporarily interrupted marketing at Grand Rapids, but the heat drying plant is being rebuilt. Part of the Rockford plant has recently burned down. It would appear that the heat-drying of digested sludge depends

for its success on conditions such as the soil and the crops and on the effort and skill of the sewage works manager in exploiting the product, as well as on the analysis. The cost of equipment and operation are a bar to such procedure in small works.

9. Enriching heat-dried digested sludge with suitable chemicals has been practiced at Rockford, Ill., but not on the entire sludge output. This appears to have been done for a particular buyer for sale in competition with heat-dried activated sludge.

10. Digested activated sludge apparently falls into the digested sludge classification when judged by its analysis and use.

11. Heat-dried activated sludge appears to have a ready market at the present time, which the plants at Milwaukee, Pasadena and Houston are unable to satisfy. This type of sludge sells retail in bags (by the bag, ton or carload) and wholesale in bulk at a somewhat lower price, determined by the market price of its content of organic nitrogen and phosphoric acid.

12. Heat-dried activated sludge is of value in the fertilizer and agricultural field for its organic nitrogen and phosphoric acid content as well as humus, and its effect as a conditioner in mixed fertilizers. As such, with suitable nitrogen content, it may justify a rail haul of 1,000 miles more or less.

13. Where organic nitrogen is required, heat-dried activated sludge can be used with safety at any reasonable time.

14. The cost of dewatering and heat-drying activated sludge on a small scale appears to have deterred those in charge of the smaller works from following this practice.

15. With the exception of the Southern California citrus orchards, no organized handling of air-dried digested sludge from a number of adjacent plants has been found. However, a large number of plants, both large and small, have developed a market for their entire output. There is no uniformity of charge and success in disposing of the sludge. In many small plants a knowledge of the uses for sludge appears lacking, although a number of operators would like information.

16. Heat-dried activated sludge is the least odorous and fresh sludge the most odorous of the various sludges. The degree of odor from digested sludge may depend on the completeness of digestion. It is therefore desirable that all air-dried or fresh sludge be turned into the soil as promptly as possible.

17. From the hygienic standpoint, heat-dried activated sludge and heat-dried digested sludge appear safe for any reasonable use in agriculture or horticulture. Digested sludge, air-dried, appears safe for such purposes if used like manure and plowed in, when preparing for a crop, and if care is taken not to apply such sludge thereafter on root crops or lowlying leafy vegetables which are eaten uncooked. Thorough digestion and air-drying, as well as storage of the air-dried sludge, afford a sufficient protection. The Committee knows of no case of sickness traceable to the use of digested sludge or activated sludge.

Fresh sludge should be regarded as only one degree removed from night soil and treated as such, being used only on forage crops and then applied and plowed in promptly thereafter.

Recommendations

1. Each sewage works operator should endeavor to popularize the use of sludge by florists, farmers and other users of fertilizer. Presenting the facts regarding sewage sludge to individual users, before farmers' associations and in farmers' publications should be helpful. Indicating the value of the sludge (supplemented by other fertilizing material if necessary) by application to lawns, flower beds, shrubs, trees and garden crops at the sewage works should prove decidedly educational.

2. More attention should be paid to the follow-up of the use of air-dried digested sludge, so that a more authoritative study of actual use and results obtained might be available for those interested.

3. Agricultural experiment stations in various states should be urged to conduct similar studies to those reported by De Turk and Fraps, by properly controlled field tests, and to determine the agricultural value of various sludges, as well as the effect of such constituents as the ether-soluble matter.

4. Laboratory workers might well continue the investigations of Ruchhoft and ascertain more definitely the life history of pathogenic bacteria during sludge digestion, and the bacterial flora of various sludges, such as raw, digested, air-dried and heat-dried.

The Committee presents this report as a summary. If errors are found or additional data are available, the Committee would welcome the information at an early date, if sent to the Chairman.

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LAYOUT AND PLAN OF OPERATION OF THE MINNEAPOLIS–ST. PAUL SEWAGE TREATMENT PLANT*

By George J. Schroepfer

Assistant Chief Engineer, Minneapolis-Saint Paul Sanitary District

Historical Review

Because of its importance in the development and design of the Minneapolis-St. Paul sewage treatment plant, the early history of the project will be briefly discussed. Even though attention was called to the polluted condition of the Mississippi River many years ago, it was not until 1923 that official recognition was taken of the situation in the form of a communication from the Minnesota Department of Health to city officials in Minneapolis and St. Paul. As a result of this action, as well as action by Interim Committees of the Minnesota and Wisconsin legislatures, an investigation was undertaken by the U. S. Public Health Service, which began in June, 1926, and lasted somewhat over a year. The Minnesota legislature in 1927 directed the formation of the Metropolitan Drainage Commission, authorized to study and investigate pollution conditions and recommend remedial measures, and this Commission functioned from August, 1927, to November, 1933. A total of 40 alternate projects with variations were analyzed, and a thorough study was made of various treatment and sludge disposal processes available to the Twin Cities. The Minneapolis-St. Paul Sanitary District was organized in November, 1933, and construction on the intercepting sewers begun in July, 1934.

Degree of Treatment

The Mississippi River at St. Paul fluctuates widely, both as to discharge—which varies from a minimum of 864 c.f.s. to a maximum estimated flow of 120,000 c.f.s.—and in the physical, chemical and biological factors which affect its ability to receive and assimilate pollution. These conditions, along with the fact that the Twin City sewage discharges into two pools, determined to a greater or lesser extent the type of treatment selected, the degree and the duration that various degrees of treatment must be maintained. In the studies of the necessary degree of treatment, the information collected on river conditions over the relatively long period of practically continuous record from June, 1926, to October, 1934, was of prime importance in adjusting sewage treatment to river requirements.

The river standards to be met have been stated only in general terms by the Minnesota State Board of Health, as follows:

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(1) The public health hazard should be reduced to a minimum, (2) the health of live stock should not be materially endangered, (3) the present public nuisance should be eliminated, and (4) fish life in the river, at least below the mouth of the St. Croix, should not be jeopardized.

These standards have been interpreted by the Sanitary District to require: that the dissolved oxygen in the stretch of the river above the Hastings Dam should, for 90 per cent of the time of each of the summer months of the average year, be maintained above 2 parts per million, that it should be above 1 p.p.m. except for relatively short periods, that some oxygen should be present at all times, and that for the preservation of fish life, sufficient oxygen, estimated at about 4 p.p.m., should be maintained below the confluence with the St. Croix river.

The pollution load on the river was estimated to reach, by 1945, a total of 1,300,000 population equivalent for the Twin City Metropolitan area exclusive of South St. Paul and Newport, from a tributary population of 910,000. Calculations using the 43-year period of river record, from 1892 to 1934, inclusive, indicate that with the above pollution load sedimentation alone will suffice to meet river standards as above interpreted, except for 12.5 per cent of the time, that sedimentation plus effluent filtration will suffice except for about 9 per cent of the time, and that sedimentation, effluent filtration plus chemical treatment to a B.O.D. removal of 70 per cent will maintain standards except for 1.5 per cent of the time.

A five-day biochemical oxygen demand removal of 70 per cent was adopted as the degree of treatment necessary to meet all reasonable river requirements. A variety of treatment processes capable of providing this removal were investigated and, after thorough study, sedimentation plus effluent filtration, augmented at times of critical river flow by chemical treatment, was adopted as the type of treatment which would most satisfactorily and economically meet the river requirements.

Some idea of the variation in treatment requirements can be had from the following: Considering river flows which obtained in the period from 1892 to 1933 and the expected 1945 pollution load, chemical treatment would be required during only 40 months of the total of 504 months, and the average B.O.D. removal required during the 40 months that chemical treatment was necessary was only 58 per cent. The 70 per cent B.O.D. removal estimated as being capable of attainment with chemical treatment will suffice during all but 8 months, in which the average removal required is 75 per cent. The highest removal indicated as being necessary during one month of the entire period is 82 per cent. Expressed in another way, sedimentation plus effluent filtration would be sufficient treatment based on past river flows for a continuous period of 14 years, and then after a 2-year period, when chemical treatment would have been required, preliminary treatment would again have been sufficient for another 12-year period. Sedimentation plus effluent filtration would have been sufficient, and no chemical

treatment required for 30 years out of the 42-year period of record. From the foregoing it will be seen that the treatment plant in this project will function essentially as a sedimentation and effluent filtration process, to which will be added, on relatively infrequent occasions, chemical treatment. In addition to giving the basic assumptions underlying the selection of the type of process, this explanation has been given to clarify in the reader's mind the reasons for some of the design features incorporated in the plant, which will be explained later.

General Plant Description

The treatment plant has been designed for an average daily flow of 134 m.g.d. expected from a tributary population of 910,000 people in 1945. The intercepting sewer leading to the plant has a capacity of 610 m.g.d., which flow will be reached on infrequent occasions during storms. The plant hydraulics are such that this entire flow can be passed through the screen and grit chambers and the settling tanks. Analyses made by the Metropolitan Drainage Commission over a limited period of time indicate the sewage will have an average 5-day B.O.D. of 200 p.p.m. and a suspended solids content of 185 p.p.m.

Described briefly, the sewage treatment plant (Fig. 1) consists of screen and grit chambers, flocculating and settling tanks, and effluent filters. The sludge disposal process consists of concentration tanks, vacuum filters and incinerators. A distinct effort was made in the design of the plant to provide a maximum of flexibility and dependability. From this standpoint, and also to secure information on the relative economy and effectiveness of various processes and chemicals, the entire plant, from the point of entrance of raw sewage to the discharge of treated effluent into the river, is divided into two distinct and separately operative divisions. Similar flexibility is obtainable in the sludge disposal processes. Features are incorporated in the design for treatment by a variety of processes. Such provisions were felt to be highly desirable when consideration is given both to the uncertain and ever-changing status of the art and to the extremely variable river requirements.

Detailed Description and Function of Various Units

Sewage Treatment

(1) *Screen and Grit Chambers.*—The intercepting sewer conducting the sewage to the screen and grit chambers is a double barrel section, each of which is 9 ft. 6 in. wide and 10 ft. deep with a total design capacity of 610 m.g.d. A by-pass is provided ahead of the screen and grit chambers so that all, or a portion of the flow, can be discharged directly into the river in emergency. Four float controlled motor operated sluice gates 60 in. by 96 in. in dimensions accomplish the diversion. From each intercepting sewer barrel the sewage passes through the two separate batteries of the screen and grit chambers, the individual units of which are described briefly as follows:

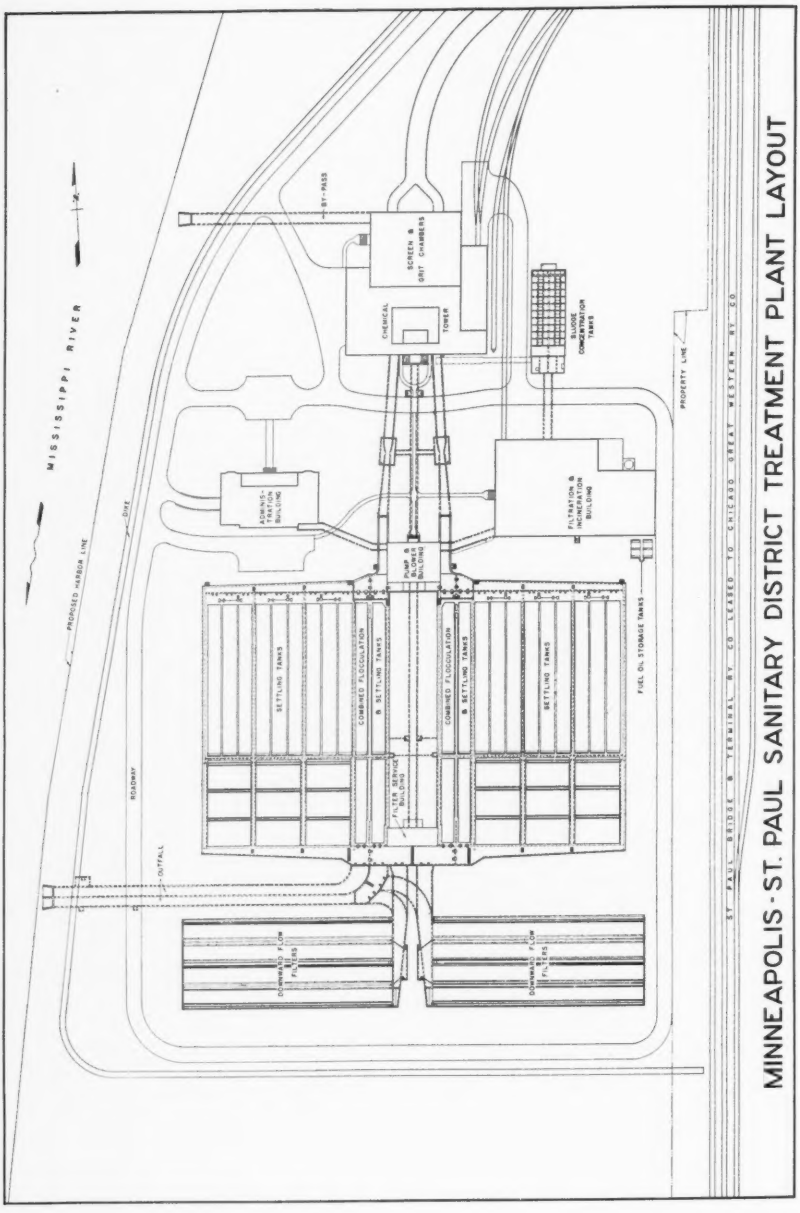

Fig. 1.—Diagrammatic layout of the treatment works.

(*a*) *Coarse Bar Racks.*—Two hand-raked racks in channels 10 ft. wide with a maximum flow depth of 10 ft. and with clear openings of 6 inches.

(*b*) *Bar Screens.*—Four mechanically and automatically cleaned bar screens with 1 in. clear openings are provided, each 10 ft. wide, with a maximum sewage depth of 8.7 ft. The screens are float-controlled in such a manner that the difference in sewage level on the two sides of the screen actuates the rake mechanism. The velocity of flow through the screen channel will be approximately 2.75 ft. per second, at 610 m.g.d., and 1.6 ft. per sec. at 134 m.g.d. The screenings will be raked into a hopper which discharges onto a 24 in. belt conveyor which transports the screenings to the service room, outside the screen and grit chamber building proper.

(*c*) *Grit Chambers.*—From the four mechanically cleaned bar screens the sewage passes through eight grit chambers each of which is 62 ft. 9 in. long from the inlet gate to outlet gate. The width of the chambers is 12 ft. and the depth of flow varies from 4.5 ft. to 9.0 ft. at flows varying from 134 to 610 m.g.d. The velocity of flow varies from 0.45 ft. per sec. at 100 m.g.d. to 1.18 ft. per sec at 610 m.g.d. The grit is removed by means of scrapers 8 ft. wide, travelling at a maximum speed of 8 ft. per min. which discharge the grit into a hopper from which it is elevated and washed by means of a 16-in. inclined screw conveyor 38 ft. long, discharging onto a 24 in. belt conveyor which conducts the grit to the service room. While provision is made for ultimate automatic control, the eight chambers will be manually controlled by motor-operated sluice gates. A total of 33 sluice gates, varying in size from 42 in. by 42 in. to 60 in. by 96 in. gates, have provided for screen and grit chamber operation and control.

The screen and grit chambers are entirely covered by a floor slab. The screen mechanisms are completely housed. The two belt conveyors on to which the screenings and grit are discharged are located in troughs, below the floor slab, which are covered with plates. The top slab of the screen and grit chambers serves as the floor for the following rooms: screen and grit chamber equipment room (dimensions 84 by 104 ft.); chemical feed and chlorination room (dimensions 78 by 80 ft.); storage room (dimensions 25 by 52 ft.). Attached to this building on one side is a garage and general utility room (dimensions 27 by 100 ft.) and on the other a service room (dimensions 30 by 124 ft.) for handling grit and screenings and for receiving and unloading various chemicals. In this room are located two screenings shredders, each with a capacity of 3,500 lb. per hr., a grit elevator and hopper for discharge of grit into trucks or freight cars, bins for emergency grit and screenings storage, a 5-ton crane equipped with a ¾ yard bucket to be used for handling grit and screenings from these bins, as well as for several other purposes.

In developing the layout for the screen and grit chambers, flexibility and dependability were considered as well as efficiency and economy of operation. Because of the multiplicity of units and their arrangement the former aims can be achieved, and by reason of design features the latter purposes can be served. Any screen can be taken out of service and likewise any pair, or any individual grit chamber can be removed from operation.

Various methods are provided for handling screenings and grit. As already explained, the screenings and grit are discharged on separate belts and conveyed to the service room. The screenings are discharged into a small hopper feeding the shredders, or in emergency into a large bin. When, and generally this will be the case, shredding is practised,

the shredded screenings will be pumped to either of several points of disposal. They can be pumped back to the sewage which has passed through the grit chambers, to the sludge concentration tanks, to the conditioning tanks, or to a centrifuge. Preference at this time appears to be in the reverse order of that with which these methods are presented.

The grit, on delivery to the service room, can be discharged either into an elevated storage hopper of 850 cu. ft. total capacity for discharge into trucks or freight cars, or in emergency, into bins of large capacity. The bucket elevator has a capacity of 30 tons per day. If transported by truck, the grit will be hauled to an area south of the treatment plant proper, a distance of 1,500 ft.

Provision is made for ventilation of the screen and grit chambers, the superstructure over these units, and the incoming sewer by means of a 20,000 cu. ft. per min. fan. All, or various fractions of the fan capacity can be applied to these different points, depending on requirements.

(2) *Chemical Control Building.*—As already mentioned, the chemical control building is a part of the superstructure over the screen and grit chamber. The total first floor area occupied for chemical control is approximately 6,300 sq. ft. Described briefly, the chemical control building houses the dry chemical feeders, chlorinators, pneumatic conveying equipment and storage bins.

(*a*) *Chemical Feeders.*—Three dry chemical feeders of the gravimetric type, each having a feeding rate infinitely variable between 400 and 2,500 lb. per hr., will be provided. These feeders are capable of use with a variety of dry chemicals. With two units in operation, the rate of feed at 134 m.g.d. can be varied from 17 to 107 p.p.m., which is believed to cover the ordinary range of operation.

The material from the feeders will be discharged directly into solution tanks, each of about 22 cu. ft. capacity, which are baffled and equipped with electric agitators. From this point the solution will pass to the surge and reaction tanks which are two in number, each with a capacity of 82 cu. ft., where the chlorine will be added when copperas is used.

In addition to the above feeders, two lime feeders similar to and interchangeable with the previously mentioned feeders will be provided, each of which has a capacity range from 400 to 2,500 lb. per hr. With two units in operation, the feeding rate at 134 m.g.d. will range from 17 p.p.m. to 107 p.p.m. Each of these units is equipped with a lime slaker, of such size that the lime will be retained about 30 minutes at a 75 p.p.m. feeding rate with 134 m.g.d. The water supply to the slaker will be automatically controlled and the slaker will be equipped with dust, vapor and clinker removal equipment.

The iron solution, if an iron salt is used, will be added at the venturi meter throat, and the lime solution will be applied in the aerated channel immediately ahead of the flocculating tanks, a distance of about 100 ft. beyond the venturi meter throats.

(*b*) *Chlorinators.*—Five solution feed chlorinators are provided each with a capacity range from 850 to 6,000 lb. of chlorine per 24 hr. With three units in operation, the chlorine dose can range up to 16 p.p.m. at 134 m.g.d. Two of the chlorinators are equipped with parts and adjustment features to provide a range from 425 to 3,000 lb. per 24 hr. In addition to their probable use for sewage treatment, one or both of these units will be used for sludge conditioning if chlorinated copperas is used for this purpose.

(*c*) *Pneumatic Conveying Equipment.*—Pneumatic conveying equipment with a capacity of 10 tons per hour is provided for unloading and elevating dry chemicals. The conveyor will deliver the chemical to a receiver located above the storage bins, from

which point it will be transported by screw conveyors to the individual bins. Because of the intermittent use of chemicals for sewage treatment and the possible difficulties of caking with certain chemicals, provision has been made for reclaiming the chemicals from these large bins and discharging them into smaller bins in the filtration and incineration building for use in sludge conditioning.

(*d*) *Chemical Storage Bins.*—A total of ten concrete storage bins, each having a capacity of approximately 2,550 cu. ft., have been provided. Chemicals from these bins will discharge by gravity into the feeders. The bins are arranged in pairs, the material from each pair discharging into a feeder. Three pairs have been assigned to storage of iron salts, or other equivalent chemical, one to the storage of lime and one unassigned at present, but intended for either iron or lime, as future requirements dictate. The bins are fitted with small holes for loosening by rodding, and the lower portion is lined with a steel shell to which an electric vibrator can be attached, if necessary. If copperas is used, the six bins will have a total capacity of about 535 tons, and the two lime bins, a capacity of 140 tons of lime, which will provide a storage of about two weeks of copperas and about one week for lime, at average treatment rates.

No definite choice of chemicals to be employed has been made, it being deemed desirable to make provision for handling and feeding a variety of dry chemicals, with the actual selection to be made dependent upon chemical quotations from time to time, and actual tests of the effectiveness and economy of various chemicals under differing conditions. In view of the periodic and relatively short time requirement of chemical treatment, only manual operation of all chemical feed and chlorination units has been provided. However, provision has been made for the future incorporation of automatic control based upon the flow and possibly also upon the strength of sewage, should conditions warrant. Two large dial indicators have been provided in the chemical control room, indicating the flow through each half of the plant, by the observation of which, and the use of charts provided, the operators can set the feeders, adjusting these as sewage flows and other conditions require. Chart recording of sewage flows and chemical additions will be made.

Plant effluent will be used for solution water. Provision has been made for future use of river water should this prove more desirable.

Dry chemicals will be received in box cars on tracks in the service room adjacent to the control room. In addition to receiving chemicals in this manner, provision has been made for unloading chemicals from barges in the future, if this procedure is found to be economical.

(3) *Flocculating and Settling Tanks.*—Included under this heading are the venturi meters, combination flocculation and settling tanks, and the settling tanks.

(*a*) *Venturi Meters.*—The effluent chamber of the grit chambers is so designed that the flow from each battery of grit chambers passes either through two venturi meters or so that the flow from either battery or fraction thereof can be passed through either venturi meter and thence to the settling tanks. Each of the venturi meters has an inlet diameter of 9 ft. and a throat diameter of 5 ft., and they are designed for a minimum flow of 43 m.g.d. and a maximum flow of 350 m.g.d. Recording and totalizing instruments are located in the pump and blower building, in the Administration Building and indicating instruments in the screen and grit chamber building.

(*b*) *Combination Flocculating and Settling Tanks.*—While designated as flocculating tanks, these units have been arranged for multiple functioning. In view of the

fact that chemical treatment will be employed only about 10 per cent of the time, it was deemed desirable to utilize the flocculating tanks as settling tanks during the balance of the time. The design provides also for their use as post-chlorination contact tanks, or grease-separating tanks, depending on requirements or desirability. Furthermore, the fact that flocculation is accomplished by aeration presents the possibility of taking advantage of the air for freshening the sewage and of accomplishing increased reduction by reason of its presence. These tanks may also be used as a by-pass channel for conducting all or part of the sewage into the outfall channel.

The tanks proper consist of two units, one adjacent to each battery of settling tanks, each unit consisting of two passes each 17 ft. 9 in. wide at the widest point, and 290 ft. long with an average water depth of 15 ft. 6 in. The walls are so shaped as to promote spiral flow produced by aeration from porous diffuser tubes. The tanks provide a detention period of 24.5 min. at the average flow of 134 m.g.d. When used as settling tanks, these tanks will therefore add 0.4 hr. to the sedimentation period. The tanks are equipped with sludge removal mechanism of the conveyor type, with porous diffuser units, and with louvre and sluice gates for accomplishing the various operations. The sludge removal mechanisms have flights 14 ft. wide. One practically continuous row of diffuser tubes is provided for each pass, having permeability ratings of 50 in the first eighth of the tanks and 30 in the last seven-eighths of the tanks. Louvre gates are provided at the front and at the back end of the center wall dividing the two passes in each tank, which are to be used for various sewage routings.

(*c*) *Settling Tanks.*—Each of the two batteries of settling tanks consists of three units each 56 ft. wide, 290 ft. long, and with an average water depth of 15 ft. 6 in. (Fig. 2). Each tank has three passes each with a width of 18 ft. The detention period in the settling tanks at the average flow of 134 m.g.d. is 2 hr., and at the maximum flow of 610 m.g.d. is 26 min.

The tanks are provided with sludge removal and skimming mechanisms. The sludge is removed by conveyor type mechanisms with flights 18 ft. wide, travelling at a speed of 2 ft. per min. to the cross collector channel which is 8 ft. wide. The cross collectors, travelling at a speed of 4 ft. per min., transport the sludge to a hopper in each tank for removal by the sludge pumps. The skimming mechanisms are driven by the sludge collector flights, and will mechanically remove the skimmings conveyed to it by the return run of the sludge conveyors, to a scum trough which runs the entire width of each battery and discharges through a scum manhole into pipes which convey it to scum pumps for final disposal. Scum can be pumped either to the sludge disposal building or to an area south of the plant for disposal by burial or burning.

A rather comprehensive system of effluent weirs has been provided. Generally described, these consist of both longitudinal and transverse weirs, the latter extending as far as 100 ft. back from the back end of the tanks, of the V-notch type, and of a total length of 480 ft. in each tank. The total weir length in the settling tanks is 2,880 ft., providing 0.047 m.g. per foot of weir length at the average flow.

The control of the division of flow between the individual tanks and the two batteries, as well as to route the flow for the various treatment processes, is accomplished by 74 sluice gates varying in size from 36 in. by 36 in. to 72 in. by 84 in. At the inlet end of each settling tank are located six hand-operated gates 36 in. by 36 in., providing a velocity of 0.65 ft. per sec. at average flow during chemical treatment. This low velocity together with baffles provided inside the tanks near the sluice gates is expected to reduce harmful inlet effects to a minimum. The relatively long weir length and the flexibility provided in their location permitting advantageous draw-off should result in favorable outlet conditions.

4. *Pump and Blower Building.*—The pump and blower building, which is located between and at the north end of settling and flocculating tanks, is 43 ft. by 60 ft. in dimensions, and consists of the main floor, the basement and the sub-basement. The sub-basement is devoted chiefly to pipes leading to and from the various equipment units, but also contains two 300 gal. per min. sump-drainage and under-drainage

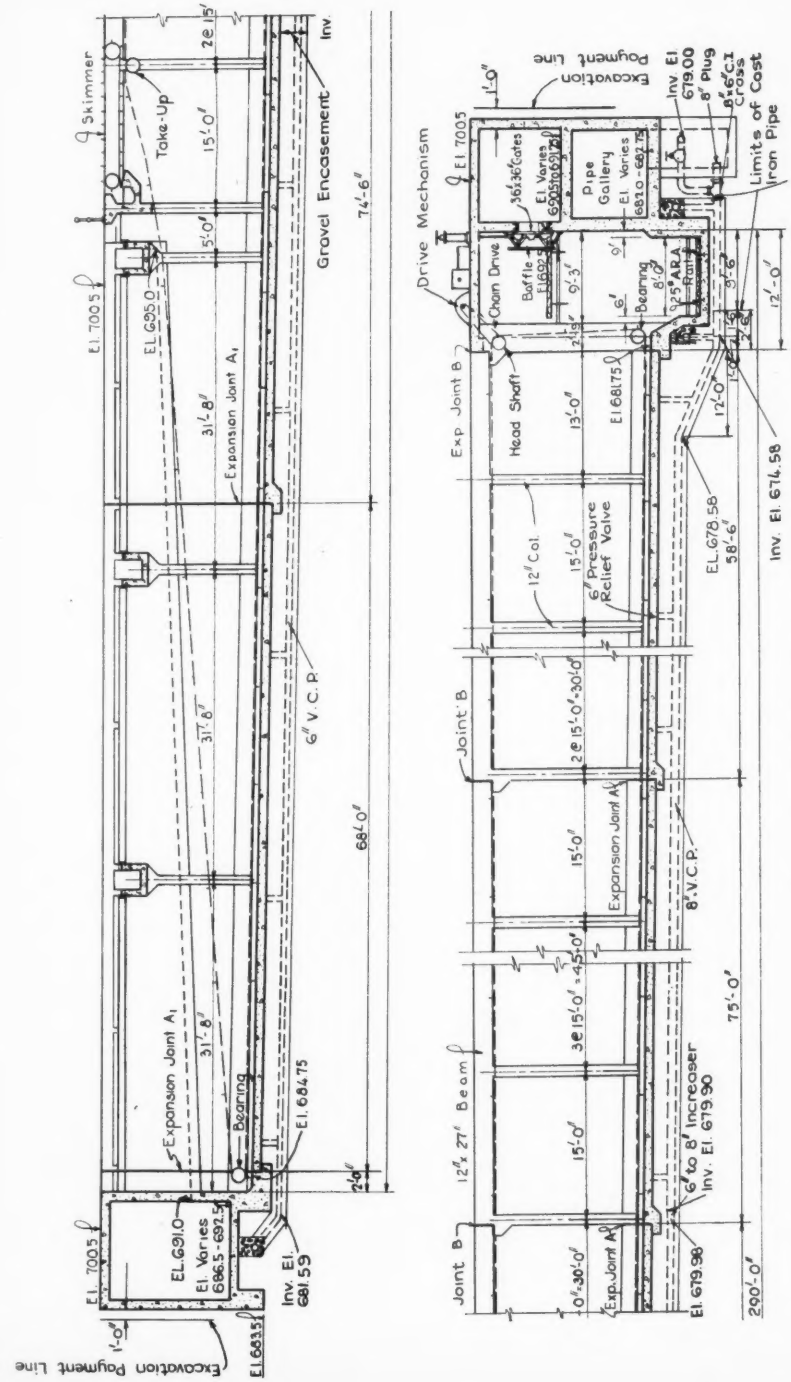

FIG. 2.—Longitudinal section of settling tank.

pumps and two 200 g.p.m. scum pumps. The basement contains eight 210 g.p.m. triplex displacement sludge pumps, two 500 g.p.m. centrifugal sludge pumps for peak and emergency purposes and one 2,500 g.p.m. tank dewatering pump. On the main floor are located three blowers, one 1,200 cu. ft. per min., one 1,800, and one 2,400, along with the switchboard for control of the various equipment, a small office and various minor miscellaneous services.

The two 300 g.p.m. sump pumps will be utilized for pumping sewage produced in the plant buildings, for pumping tunnel drainage and for under-drain pumping. For sludge pumping it is expected that ordinarily the 210 g.p.m. displacement sludge pumps will be used, in which case the time required to pump the 360,000 gal. per day of sludge expected during average conditions under plain sedimentation, will be approximately 3.5 hours. Under average conditions during chemical treatment, about 875,000 gal. per day of sludge is expected, when it is expected that in addition to the displacement pumps, one or both of the 500 g.p.m. centrifugal sludge pumps will be employed, when the pumping time will vary from 7.0 to 5.5 hours, respectively. Under conditions of maximum sludge production, with all pumps in operation, a total of about 13 hours of pumping will be necessary.

The blower capacity is designed for variation in the quantity from 1 c.f.m. per lineal foot of tank with the smallest blower in operation, to 4.7 c.f.m. with all blowers in operation, with various intermediate quantities with different blower combinations.

(5) *Effluent Filters.*—The effluent filters are of the downward flow magnetite sand type and are eight in number and divided into two batteries. The total filter area is 31,200 sq. ft. which provides a filter rate of 3 gal. per sq. ft. per min. at average flow of 134 m.g.d. Each filter bed is 16 ft. wide and 244 ft. long (Fig. 3). The filter bed will be cleaned by a solenoid which passes over the bed at a speed variable between 4 and 8 ft. per min. The wash water will be pumped by a pump of 300 g.p.m. capacity into wash water troughs depressed below the sewage level to prevent freezing. These troughs will feed into sumps from which the wash water will be conducted to pumps located in the filter service building. The beds will be automatically cleaned when the differential head exceeds a pre-determined amount.

After passing through the filters, the effluent discharges into a double barrel outfall sewer, each barrel being 10 ft. by 10 ft. in dimensions. Sluice gates are provided for preventing back-up during high river stages.

(6) *Filter Service Building.*—The filter service building, 20 ft. by 60 ft. in plan, is located between the two batteries of settling tanks, immediately north of the effluent filters, and consists of a main floor and a basement. In the basement are located three 1,500 g.p.m. wash water pumps, two small water seal pumps, two 300 g.p.m. sump pumps, two pumps of 60 g.p.m. and 300 g.p.m. capacity, and two pumps each of 450 g.p.m. to pump plant effluent, or with slight rearrangement river water,

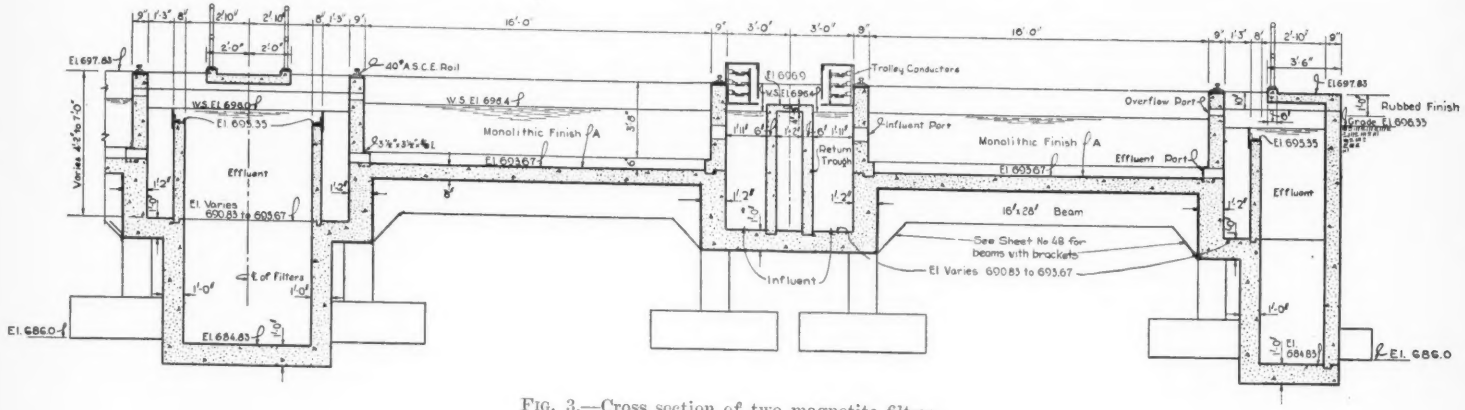

FIG. 3.—Cross section of two magnetite filters.

for use in sluicing ash or dissolving and transporting chemicals. In this basement are also located six of the eight automatic sewage samplers provided.

On the main floor of this building three motor-generator sets are located which are to be used for filter cleaner operation. Each motor is of 50 h.p. capacity, operates on 220 volt alternating current, and by means of the generator produces direct current at 250 volts. On this floor is also located the switchboard for filter operation, as well as a ventilating fan for exhausting air from the basements of the filter service and pump and blower buildings and the various tunnels.

(7) *Miscellaneous Treatment Features.*—An interesting feature of the plant is the compact grouping of main buildings in spite of the relatively large area of 15 acres occupied. The screen and grit chamber and chemical control building, the pump and blower building, the laboratory and administration building, and the filtration and incineration building are so arranged as to reduce the cost of carrying the various services to the different buildings, and to generally simplify plant operation. This arrangement has made it possible to connect the buildings with tunnels, for the use of operating personnel, and for carrying in an accessible location the large number of pipes between the various buildings.

The head loss through the entire plant varies from 4.0 ft. at the average flow of 134 m.g.d. to 10.7 ft. at the design basis of the intercepting sewer, viz., 610 m.g.d. The plant is set at an elevation relative to river stages that the entire treatment process can be employed until the river reaches an elevation of 696.0, which stage is exceeded but 2 per cent of the time, and represents a river discharge of about 50,000 cu. ft. per sec. With higher river flows the effluent filters can be bypassed and the settling tanks operated until the river stage exceeds 698.0. A freeboard, at maximum flow of 1 ft. 10 in., has been provided in the settling tanks, and 1 ft. 9 in. in the effluent filters. One foot of head for future utilization has been provided between the settling tanks and effluent filters. Unusual hydraulics problems were created by the extremely wide variations in sewage flows for which provision was made.

Automatic sampling at various points has been included. The following samples will be taken of each half of the plant: (*a*) grit chamber effluent, (*b*) settling tank effluent, (*c*) post-chlorination tank effluent, and (*d*) filter effluent.

In view of the fact that at the inlet end the settling tanks are 5.5 ft. below ordinary river elevations, provision was incorporated in the design for an underdrainage system under the tanks, connected to pumps in the pump and blower building. A further safeguard is provided in the incorporation of pressure relief valves in the tank bottoms and outside walls, in the event the pumps for any reason are not operated.

Sludge Disposal

(1) *General.*—The sludge removed from the settling tanks will be pumped to the sludge concentration tanks. After concentration for a desirable period of time, the sludge will be conducted to the conditioning tanks, thence to vacuum filters, and finally to the incinerators. The sludge quantity is estimated to vary from an average of 360,000 g.p.d. containing approximately 155,000 lb. dry solids, to a maximum of 2,135,000 g.p.d. The peak quantity of solids including chemicals is estimated to be 645,000 lb. dry solids per day.

(2) *Concentration Tanks.*—Two such tanks are provided each 95 ft. long, 18 ft. wide, with an average water depth of 24 ft. (effective capacity of 41,000 c.f. each), provided with sludge collector mechanisms and means for removing scum. The tanks are completely covered, the middle third being provided with easily removable wood covers for access. During normal operation it is expected that only sufficient capacity will be utilized to obtain satisfactory concentration consistent with efficient filter operation, the remaining space being held in reserve for peak loads. Provision has been made in the design for adding raw sludge at various points in the tanks, and for withdrawing supernatant at various elevations and at different locations as operation may indicate to be most effective. The supernatant will be returned to the conduit immediately ahead of the settling tanks.

(3) *Filtration and Incineration Building.*—In this building the following services are located: (*a*) vacuum filters and appurtenances, (*b*) incinerators and appurtenances, (*c*) centrifuge, (*d*) shop, (*e*) heating and (*f*) electrical equipment. The main floor area is allocated as follows: vacuum filters (71.5 by 96 ft.), incinerators (60 by 71.5 ft.), storeroom 25 by 31 ft.), shop (35 by 70 ft.), track service room (25 by 67 ft.), and electrical service room (23 by 35 ft.). In general the building has a main floor and a basement, except for the incinerator room, which has six floors, and the shop and track service room, which have only a main floor.

(4) *Vacuum Filters.*—The sludge from the concentration tanks is conveyed by pipe lines in tunnel to two sumps in the building which feed two bucket elevators each with a maximum capacity of 480 g.p.m. These elevators discharge into two air-agitated conditioning tanks each with a capacity of approximately 2,000 gallons. From these tanks the sludge discharges by gravity into six vacuum filters arranged in two batteries of three units each. The arrangement is such, and space has been provided for, the addition of two filters.

Each filter is 11 ft. 6 in. in diameter and 14 ft. long, and has an effective filter area of 500 sq. ft. The filter rates with six units in operation will vary from 2.5 to 4.0 lb. of dry solids, including conditioning chemicals, per sq. ft. per hr., under average conditions during plain sedimentation and chemical treatment, respectively. The peak filter rate is estimated to be about 8.0 lb. per sq. ft. per hr. The filtrate will be returned to the conduit ahead of the settling tanks. The filter cake

will be discharged onto 24 in. belts which are reversible, so as to discharge onto either of two main belts which receive the cake from the two batteries of filters and conduct it, after weighing, to the incinerators.

Among the main appurtenances of the vacuum filters may be mentioned the three vacuum pumps each with a capacity of 1,850 c.f.m., the three blowers each with a capacity of 800 c.m.f., and the three filtrate pumps each with a capacity of 250 g.p.m. The two weighing scales each have a capacity range of from 2 to 30 tons per hour.

(5) *Incinerators.*—Three incinerators of the multiple hearth type are 22 ft. 3 in. outside diameter, with eight hearths, each incinerator having a nominal capacity of 60 tons of dry solids per 24 hours. Space is provided for the addition of a fourth unit.

The conveyor belts are so designed that a portion or all of the cake can be discharged in trucks for dumping or burial. This method of operation will be resorted to during times of extremely unusual peak solids production, or during incinerator shutdown. The incinerator ash, expected to range from 35 to 150 tons per day, will be discharged into hoppers from which it will be sluiced to ash pumps, whence it will be discharged at points 600 to 1,500 ft. south of the treatment plant proper. The main appurtenances of the incinerators are the three preheaters, the three hot air fans, each with a capacity of about 11,000 c.f.m., and the three hot gas fans, each with a capacity of about 36,000 c.f.m.

(6) *Chemical Handling and Feeding.*—Chemicals for sludge conditioning will be received in freight cars in the track room of the filtration and incineration building. A pneumatic conveying system with a capacity of 6 tons per hour has been provided for unloading dry chemicals and discharging into storage bins. A total of four storage bins with a combined capacity of about 2,700 cu. ft. have been installed.

Chemical feed equipment is installed for feeding lime with either chlorinated copperas, ferric sulfate or ferric chloride, the use of which will depend on the efficiency and market prices of the various chemicals from time to time.

Two gravimetric lime feeders and slackers, each with a capacity range from 50 to 1,500 lb. per hr., as well as two copperas or ferric sulfate feeders, each with a capacity range from 50 to 1,500 lb. per hr., have been installed. In addition to the above feeders, two solution feeders for ferric chloride have been provided, each with a capacity range from 12 to 120 gal. per hr. The rate of chemical feed from all of the above feeders will be controlled from the drive shaft of the bucket elevators so that the chemical quantity will be automatically varied with the volume of sludge filtered.

(7) *Miscellaneous Sludge Disposal Features.*—Included as a part of the filtration and incineration building is a shop with an area of about 2,500 sq. ft., in which are located two lathes, a drill press, a radial drill, a pipe threading machine, a shaper, grinder, wood saw, etc. The boiler room has two 60 h.p. horizontal return tubular boilers. The electrical transformers and switching equipment have a capacity of

2,100 k.v.a. Power will be received at 4,000 volts and except for a few pieces of equipment and lighting will be used at 220 volts. A 190 h.p. gasoline engine-driven generator is provided for operating various essential services in the event of power failure. The incineration room will be cooled by circulating the air from this room into the filter room under certain conditions and at other times exhausting through the roof. In the basement of the filter room is located a centrifuge for dewatering shredded screenings.

Laboratory and Administration Building

This building, which has two floors, has a ground floor area of about 6,600 sq. ft. The basement is devoted to a garage, a dining room, a shower and locker room and an equipment room which contains the air conditioning equipment, emergency boiler and various other services. The main floor is used for engineering and administrative offices, and the second floor is devoted to laboratory purposes. The laboratory proper has an area of 2,050 sq. ft. and consists of a total of six rooms, one of which is an office. The furniture is entirely of steel and a number of features have been included to add to its efficiency and usefulness.

Miscellaneous Plant Features

The architecture of the various buildings is of the simple modern type, the appearance of which will be enhanced by appropriate landscaping. The plant is protected on the river side by a brush mattressed and rip-rapped dike, which in general is about three feet higher than the plant grading. Water for general plant purposes will be from the city supply and an adequate distribution system has been provided. A complete drainage system has been installed which ordinarily discharges by gravity into the river, but during flood stages will be pumped by a 3,000 g.p.m. pump.

A total of 65 pumps are included in the plant varying in capacity up to 3,000 g.p.m. The total number of motors in the entire plant is approximately 350 and they vary in size up to 75 h.p.

Construction on the treatment plant began in September, 1935, and is expected to be completed by the spring of 1938.

The construction cost of the treatment plant can not as yet be definitely determined, but the total of bid prices on contracts awarded to date is $3,425,797.48, which with the estimated additional future construction cost of $139,944.28, and 5 per cent for contingencies and omissions, is expected to bring the total construction costs to $3,750,000, or $28,000 per m.g. The cost may be approximately divided between the various units, as follows:

Screens and grit chambers and chemical tower with appurtenances, $540,000, settling tanks, effluent filters and appurtenances, $1,630,000, filtration and incineration building and appurtenances, $1,240,000, lab-

oratory and administration building, $175,000, and miscellaneous, $160,000.

A total of 33 contracts were awarded for the construction of the plant. In general, the furnishing and installation of equipment of any magnitude was contracted for separately, to insure the placing of responsibility. Maintenance bonds in the amount of 50 per cent of the contract price, for a period of one year, have been required of all equipment contractors to guarantee the successful and satisfactory operation of the equipment, and its freedom from defects in material and workmanship. On certain equipment performance guarantees have been required in addition.

The Minneapolis-St. Paul Sanitary District is under the direction of a Board of Trustees consisting of three members from each of the Twin Cities, and a member from the State at large. C. C. Wilbur is Chief Engineer of the District, and William N. Carey is Project Engineer for the Federal Emergency Administration of Public Works.

THE BEAUTIFICATION AND IRRIGATION OF GOLDEN GATE PARK WITH ACTIVATED SLUDGE EFFLUENT *

By Charles Gilman Hyde

Professor of Sanitary Engineering, University of California, Berkeley

A Brief Review of the Problem and Project

Golden Gate Park, which has been made one of the most beautiful and satisfactory recreation areas in the world, has been wrested from the sand dunes of the Richmond-Sunset District in the west-central portion of the City of San Francisco. Water has always been a relatively costly and at times none-too-abundant item among the city's public utilities. The long dry seasons with virtually no rainfall compel irrigation. The demand for irrigation becomes more important and the quantitative demands are greater if the soil is exceedingly porous and lacks humus. Such is the case in Golden Gate Park.

Local water supplies from wells have been developed to the utmost but have been inadequate, particularly during long-continued periods of drought.

Many years ago, before the residential area contiguous to the westerly portion of the park had become built up, raw sewage was used to irrigate certain areas by means of ditches. The sewage was obtained from main sewers in Fulton Street, constituting the north boundary of the park, and in Lincoln Way, bordering the park on the south. The inesthetic quality of this procedure and the odors caused thereby gave rise to serious complaints when people began to live in the vicinity. Eventually, despite the great need for irrigation water, the practice of using raw sewage had to be abandoned.

By 1926, because of the excessive cost of water from the public supply, the Park Commission began to give consideration to the possibility of treatment of the available supply of sewage to the condition where it could be employed with satisfaction, from esthetic and hygienic standpoints, for irrigation purposes.

In 1932, arrangements were made with the McQueen Sewage Disposal Company for the construction of an activated sludge treatment plant having a nominal capacity of one million gallons per day. Construction was begun in April and completed in August of that year.

Since its completion the chlorinated plant effluent has been used in the westerly half of Golden Gate Park. Lakes, artificial brooks and waterfalls have been created and maintained; irrigation by means of ditches has been practised on occasion; and a limited amount of sprinkling by pressure pipe and hose has been possible, notably in the stadium.

* Presented at the Ninth Annual Convention of the California Sewage Works Association, San Jose, Sept. 14, 1937.

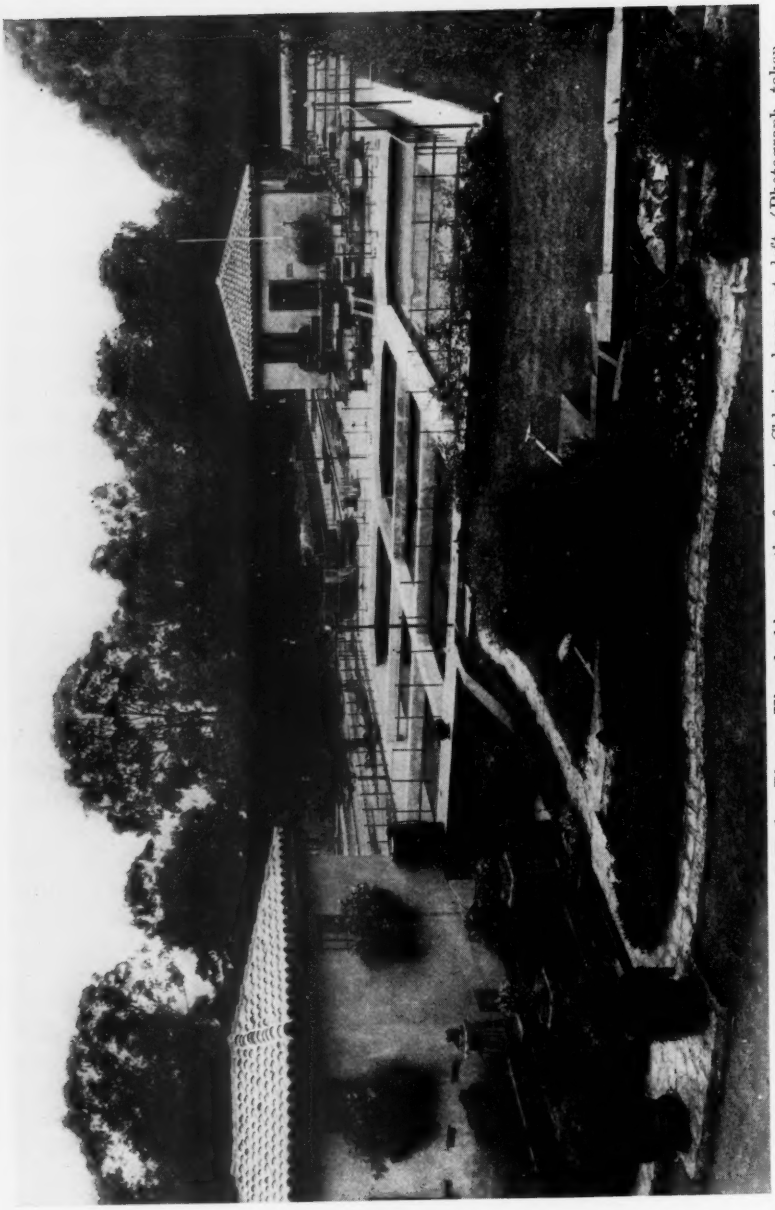

FIG 1.—Golden Gate Activated Sludge Plant. View looking south of west—Chlorine house at left (Photograph taken September 3, 1934, by City Photographer).

The extraordinary extent to which the park throughout its area is utilized, and the intimacy of this use for recreation purposes, demand that the treatment works operate without nuisance due to odors and noise and that the effluent be clear, stable and hygienically safe. This result has been achieved with commendable uniformity and continuity.

General Outline of the Beautification—Irrigation Works

The works which are involved in the beautification and irrigation of the park with treated or salvaged sewage are:

(1) a diversion chamber in the Lincoln Way sewer at Twentieth Avenue;
(2) an influent or supply pipe line to the treatment plant;
(3) an activated sludge sewage treatment plant having a nominal capacity of one million gallons per day;
(4) delivery conduits to Elk, Mallard and Metson Lakes;

Fig. 2.—Beautification—Irrigation of Golden Gate Park. Metson Lake, from west end looking east. This lake commonly receives the effluent directly from the plant.

(5) an artificial brook, with cascades, leading from Metson Lake to the most southerly lake of Chain of Lakes, about two thirds of a mile distant;
(6) a pressure pipe line, with hose irrigation, for the stadium;
(7) various temporary ditches for occasional irrigation of dry areas, as at present, for example, in the woods east and southeast of Metson Lake.

Metson Lake is supplied with water, also, from Stow Lake to which water is pumped from wells in the park. Chain of Lakes, therefore, through the connecting artificial brook, is supplied in part from this source and in part with sewage effluent.

Climatic Conditions

The average rainfall in San Francisco for the 88 seasons (July–June), from 1849–'50 to 1936–'37, inclusive, has been closely 22 inches,

of which nearly 85 per cent has fallen during the five months, November to March. There have been eight exceedingly dry seasons with less than 12 inches of rainfall. The minimum observed seasonal rainfall occurred in 1850–'51 and amounted to only 7.42 inches, or 34 per cent of the mean. The maximum seasonal rainfall, occurring in 1861–'62, totaled 49.27 inches, or nearly 225 per cent of the mean. On the average there have been only 67 days per year when the precipitation was measurable. Of these, 18 days, or 27 per cent, are to be found in the seven-months period, April to October.

FIG. 3.—Beautification—Irrigation of Golden Gate Park. Cascade from Metson Lake showing developed shrubbery.

Weather Bureau records attest to the equableness of San Francisco's climate and to the possibility of the use of parks and playgrounds practically throughout the year. The data show that only twice in 63 years has the temperature dropped to the freezing point, with an absolute minimum of 27° F. Only seven times during that period has it fallen below 35° F. Only twice has a temperature above 100° been recorded. Extremes approaching these limits occur rarely and are commonly of short duration, perhaps two or three days at most. The average temperature throughout the day does not vary more than 15°, nor is the range throughout the year much more than 15° for corresponding hours of the day. The mean annual temperature for 64

years of record is 56.4°, with an average daily minimum value of 50.2° and an average daily maximum value of 62.5°. The mean temperature for September, the generally warmest month, is 68.3° and that for January, the coldest month, 44.7°.

A remarkable uniformity prevails, also, with respect to the direction and velocity of the winds. There are periods of calm but they seldom continue throughout a day. The winds blow with great regularity from the west and southwest. There is some variation according to seasons. For example, winds from the north, northwest and northeast occur most frequently during the winter and spring months, and southeast winds prevail during periods of rain. In the early morning hours, even in the summer season, winds may blow from the north and northeast. During the period April–October, the wind blows from the southwest and west more than 75 per cent of the time. The record for the

FIG. 4.—Beautification—Irrigation of Golden Gate Park. Middle lake of chain of lakes—looking south.

20-year period 1891 to 1910, inclusive, gives an average annual wind velocity of 9.7 miles per hour. July is the month of average maximum velocity, namely, 13.4 miles, and December that with the lowest, 6.7 miles per hour. The maximum average hourly rate, 21.5 miles, occurs normally between 4 and 5 o'clock on July afternoons. The lowest average rates, around 6 miles per hour, appear in the mornings in February and from September to December, inclusive.

During the four years, 1932–1935, inclusive, the Weather Bureau reports an average of 34 days per year with light fog and 8 days with dense fog. The hours of sunshine are reported to have averaged, during that period, 68 per cent of the possible value.

These statistics have been presented to indicate the extent to which the park can be used for recreation purposes and the necessity for adopting an irrigation procedure which shall meet very rigorous esthetic and sanitary, as well as physical, requirements.

Golden Gate Park

Golden Gate Park embraces 1013 acres, or nearly 1.6 square miles. It is approximately one-half mile wide, north and south, and three miles long, east and west. In addition there is the pan handle, so-called, a parked area one block wide between Oak and Fell Streets. Its length eastward from Stanyan Street to Baker Street is somewhat over three-fourths of a mile.

It would be impossible to describe the wealth of botanical material with which the park has skillfully, but laboriously, been planted.

It is boasted, and rightly, that adequate provision has been made in the park for almost every known sort of outdoor sport, except swimming.

There are upwards of 25 miles of improved roadway and other miles of bridle paths and trails. There are waterfalls and lakes with wild waterfowl in abundance. There are woods and spacious lawns

Fig. 5.—Beautification—Irrigation of Golden Gate Park. Elk Lake, from the west. Created in 1936. Filled and maintained with sewage effluent.

and gardens of flowers and shrubs, all containing contributions from every part of the globe.

It is said that the use of the street sweepings of the city in the early years furnished the humus necessary to plant life and served to check the movement of sand by the wind.

The park contains such famous institutions as the Museum of the Academy of Science, the de Young Museum, the Steinhart Aquarium. There is the Beach Chalet and the Japanese Tea Garden. Here and there are wild animals: buffalo, elk, deer, bears and many kinds of caged birds.

Speaking of breathing spaces, Charles Caldwell Dobie in his Book "San Francisco—A Pageant" (D. Appleton-Century Company, 1934), has these things to say concerning Golden Gate Park:

> It was not until the city had swung into its stride that its inhabitants remembered the leafy breathing spaces of their native States. When they did, the only tracts avail-

able for park purposes were stretches of dunes harried by the wind. Even these were in the hands of influential men who claimed them by virtue of squatters' rights. In the end, the alleged owners yielded up a thousand acres of their holdings in exchange for proper deeds from the city for what they retained. But the lands which came under civic control were the butt and jibe of the entire community. Make a park out of a thousand acres of worse than desert lands! Make trees grow in sand blown hither and yon by a biting wind from the sea! As well attempt to cultivate the mountains of the moon.

The ground for Golden Gate Park was acquired in 1870 and for the first seventeen years four superintendents came and went—Hall, Pritchard, Hennessy, and McKewen. In 1887, a young landscape gardener from Scotland received the appointment as Park Superintendent. Mr. McLaren still retains his post after a lapse of forty-five years. This is not only a record in park administration but one of the high spots of prolonged service for the city and county of San Francisco.

The four gentlemen, who preceded John McLaren, deserve whatever credit is due for pioneering, but the park as it stands today is the creation and life-work of a single man. It is a triumph in more ways than one, but its outstanding claim to fame lies in being artificially built into a thing supremely natural. Visitors marvel when you tell them that practically every tree, every shrub, every blade of grass has been planted.

Once you leave the Band Concourse behind, your paths lead you through an ever-increasing wildwood until you achieve the ocean front. Lakes ruffled by the dark beauty of black swans and filled with sprig and teal and mallard in the winter months, nestle in the hills. Cataracts leap down from the heights. Maiden-hair fern and mimulus tremble before the ripple of waters. Quail rise in soft thunder from the brush. Cotton-tailed rabbits dart across the bridle paths. Squirrels dog your steps for plunder and, failing, content themselves with searching for truffles under a thick carpet of pine needles.

Often, in some sheltered glade, one comes quite suddenly upon acres of bloom—rhododendrons in May, dahlias of incredible diameter in August, purple patches of South African heather in December. By the end of January, the air is fainting in the perfume of ten thousand acacia-trees, and the gaunt blue eucalyptus is wreathed in bride-like white. In March the sun-drenched yellow broom begins to blossom.

Upon the distinguished Superintendent of Golden Gate Park, to whom it owes its remarkable development, was conferred, a few years since, the honorary degree Doctor of Laws by the University of California. This is but one of the ways in which Dr. John McLaren's contribution to the public welfare has been recognized.

It must be apparent that a great public recreation area such as Golden Gate Park can only be built upon intelligence and imagination, perseverance and hard work, money and material, fertilizer and water. All of these have been bestowed upon Golden Gate Park and have created a veritable paradise.

The Activated Sludge Sewage Treatment Plant

The activated sludge sewage treatment plant which, since 1932, has furnished its effluent for the beautification and irrigation of the westerly half of Golden Gate Park, was designed to have a nominal capacity of one million gallons per day. Its main features are as follows:

(1) A bar-rack and by-pass structure containing two small manually cleaned bar racks and a by-pass weir permitting floating material such as grease and oil, and excess sewage to be diverted to a near-by sewer crossing the park at a lower elevation.

(2) A small diversion chamber permitting the use of either or both of two primary settling tanks.
(3) Two primary rectangular settling tanks having a combined holding capacity of approximately 100,000 gallons. These are normally operated in series.
(4) Two rectangular spiral-flow aeration tanks, operated in series, with a combined holding capacity of 330,000 gallons.
(5) One secondary rectangular settling tank having a holding capacity of about 100,000 gallons.
(6) A chlorination contact chamber with a holding capacity of approximately 19,000 gallons.
(7) Two chlorinators supplied by ton cylinders substantially housed beside the chlorination contact chamber.
(8) Two parallel, contiguous, rectangular sludge digestion tanks, located between the two aeration chambers, having a holding capacity of 22,300 cubic feet.
(9) Three sludge drying beds, utilizing the natural sand at the site, and having a net area of about 13,000 sq. ft.
(10) A laboratory and blower house.
(11) A gas holder of 750 cubic feet capacity, as yet not placed in service.

The works have been well and artistically designed and constructed. Much attention has been given to the planting and landscaping of the site so that it is rapidly becoming a really beautiful spot and an ornament rather than a disfigurement in the Park.

The treatment works were designed by Mr. Henry Elrod, Consulting Engineer, Houston, Texas. They were constructed by the McQueen Sewage Disposal Company under the personal direction of Mr. Frank McQueen. They were supervised by Mr. Earl Clements, Engineer and Assistant Park Superintendent, representing the Board of Park Commissioners.

The sludge handling equipment and aerators were furnished by the Link-Belt Company. The blowers, four in number, having a rated capacity each of 390 cubic feet per minute under three pounds per square inch pressure, are Connersville Victor-Acme, No. 715. The two chlorinators are Wallace and Tiernan, of manually controlled vacuum solution-feed type.

The plant was built, for the most part, by "distressed" or relief labor. The cost is not known in detail but with the additional primary settling tank constructed in 1936, it has been roughly estimated at about $85,000.

The annual cost of operation, exclusive of interest and depreciation, may perhaps reasonably be taken at about $7500. If an allowance of 10 per cent be made to cover the fixed charges of interest and depreciation, the total annual cost would become $16,000.

Since January, 1934, the plant has been most efficiently operated

by Mr. Archie F. Fraser. In recent years he has been assisted by Mr. Bernard J. Boyle.

Volume of Sewage Treated

In August, 1933, the plant was equipped with an Improved Parshall Flume to measure the effluent as it is discharged from the chlorination contact chamber. A continuous record of the volume of sewage treated has not been obtained for various reasons.

The average daily output of the plant during certain periods in the years 1933 and 1934 was determined by Mr. Edwin W. Barbee, a senior student in the University of California in connection with his thesis studies of its performance. For the 11 weeks from September 30 to December 16, 1933, the figures were as follows:

Average	= 550,000 gal. per 24 hr.
Maximum week	= 740,000 " " " "
Minimum week	= 320,000 " " " "

During 7 consecutive weeks from February 10 to March 31, 1934, the figures were:

Average	= 490,000 gal. per 24 hr.
Maximum week	= 600,000 " " " "
Minimum week	= 410,000 " " " "

The average output for the 18 weeks was about 530,000 gallons per day.

Mr. Fraser states that the output of the plant under normal conditions at present reaches a peak of about 750,000 gallons during the forenoon hours and a low level of perhaps 130,000 gallons during the hours following midnight.

The output is limited by the available supply of sewage and of air. If the blower capacity were increased, with the improved pre-treatment consequent upon the construction of the additional primary settling tank, it appears that the plant would be able to treat effectively a uniform flow of one million gallons per 24 hours provided this quantity were available in the Lincoln Way main sewer at the point of diversion. This latter condition, however, does not obtain.

Source and Character of the Sewage Treated

The sewage treated by the plant is obtained from the Lincoln Way main sewer through a diversion structure in the vicinity of Twentieth Avenue. The area tributary to this diversion is perhaps 1350 acres or about 2.1 square miles. The population resident in this district is variously estimated between 10,000 and 15,000 persons. The homes are for the most part of good class.

The volume of sewage flow has not been measured at the point of diversion. Gagings made elsewhere in the Sunset District indicate

that the contribution of sewage may be in the neighborhood of 60 gallons per capita per day, the general maximum being at the rate of 100 gallons and the general minimum at the rate of somewhat less than 30 gallons per capita per day.

The tributary district contains two large hospitals and a restricted business section. Otherwise the area is entirely residential. It is sewered by the combined system.

The dry weather sewage is of concentrated character and on Mondays and Tuesdays, particularly, it contains large quantities of grease and soapy material. Occasionally there are heavy contributions of oil.

Drainage wastes from the composting of great quantities of manure have recently been discharged directly into the influent pipe line. This practice has resulted at times in a high discoloration of the effluent and has doubtless imposed an additional burden upon the plant.

For various reasons no continuous series of samples have been collected and analysed to demonstrate the character of the raw sewage. In connection with their thesis studies of plant performance, Mr. Frank Giusto, during the period September, 1932 to April, 1933, and Mr. Edwin W. Barbee, during the period September, 1933 to March, 1934, collected and analysed certain samples of raw sewage and effluent. The plant operators, Messrs. Fraser and Boyle, have also done some analytical work. The several results are presented in the following table.

Results of Analyses of Screened Sewage Treated by the Activated Sludge Process at the Golden Gate Park Plant

Results in Parts per Million

	By Barbee* 8/33–3/34			By Giusto† 8/32–4/33
	Avg.	Max.	Min.	Avg.
Suspended Solids, Total	480	900	190	410
Suspended Solids, Volatile	380	860	90	—
5-day B.O.D.	320	480	210	400
Alkalinity as $CaCO_3$	270	290	260	270
Grease	38	41	24	39
Chlorides	90	100	85	80
Hydrogen-Ion Conc. as pH	7.2	8.0	6.8	7.3
Temperature, Deg. F.	69.5	77.0	66.2	—

* Four-hour composites on Saturday mornings only.

† Composite 24-hour samples to represent various days of the week from Tuesday to Sunday

Character of the Plant Effluent

For the purposes which have been briefly described above it is obvious that the effluent must be continuously low in suspended solids, must have a high degree of stability and must be hygienically safe.

The available physical and chemical data defining the quality of the effluent of the plant are presented herewith.

Results of Analyses of Unchlorinated Effluent of the Golden Gate Park Activated Sludge Plant

Results in Parts per Million

	By Barbee* 8/33–3/34			By Giusto† 8/32–4/33
	Avg.	Max.	Min.	Avg.
Suspended Solids, Total	27	180	0	15
Suspended Solids, Volatile	17	100	0	—
5-day B.O.D.	15	85	0	10
Dissolved oxygen	2.0	5.4	0.3	1.7
Relative Stability, Per Ct.	95	96	11	—
Hydrogen Ion Conc. as pH	7.2	7.5	6.8	7.3
Temperature, Deg. F.	67.4	72.0	61.7	—

* Four-hour composites on Saturday mornings only.

† Composite 24-hour samples to represent various days of the week from Tuesday to Sunday.

The Department of Public Health of the City and County of San Francisco, Dr. J. C. Geiger, Director, has assumed a degree of responsibility for the hygienic character of the plant effluent. From time to time since February 17, 1933, bacteriological samples of the chlorinated plant effluent have been collected by an inspector of the department and have been examined in its laboratory. The visits of the inspector are irregular and unannounced. A total of 173 samples had been collected up to August 12, 1937. Total counts at 37° C. have been made and the presumptive presence of B. coli determined in various dilutions. It has been the practice to inoculate two tubes each with 10, 1, 0.1, 0.01 and 0.001 c.c. of every sample. The results are summarized in the following table.

It is the current practice to apply to the plant effluent at the entrance to the contact chamber 28 pounds of chlorine per day, the rate being maintained as uniform as possible. The pressure of the water supply available at the plant is always insufficient. Moreover, it fluctuates widely and at times seriously affects the operation of the chlorinators. Despite this handicap, the bacteriological results, as related to the presence of B. coli, have been remarkably good since the plant operation was taken over by Mr. Fraser. No single sample collected during 1937 has shown positive results in any quantity of sample examined, not even in 10 c.c.

The writer does not have the information at hand to enable him to compare these results with the performance of other plants. It would seem to him that they are extremly meritorious and that the plant operators should be highly commended for their excellent achievements.

The plant performance as related to suspended solids and B.O.D. of the effluent has been steadily improved. In the writer's opinion it would be difficult to find anywhere an activated sludge effluent of generally better appearance and quality than that consistently produced at the Golden Gate Park plant.

The water supply of the park, other than the sewage effluent in question, is derived from the ground. Stow Lake and other lakes supplied by ground water are generally heavily infested with algae and are normally very green. The growth of algae is stimulated by the nitrogen in the plant effluent so that the lakes supplied from this source are even more deeply tinged with green and are commonly turbid on this account.

Golden Gate Park Activated Sludge Sewage Treatment Plant. Results of Bacteriological Examinations of Plant Effluent

Items	Year				
	1933	1934	1935	1936	1937*
Samples Collected	72	30	36	28	7
Colonies—37° C.					
Samples below 100	60	26	30	25	1
Average count	450	150	210	36	1,400
Maximum count	10,000	1,700	3,000	200	5,000
Minimum count	1	2	1	0	45
B. coli Determination. Tubes, Each Dilution	144	60	72	56	14
10 c.c.—Positive	75	20	13	7	0
%Positive	52	33	18	12	0
1 c.c.—Positive	40	2	6	3	0
%Positive	28	3	8	5	0
0.1 c.c.—Positive	17	0	6	1	0
%Positive	12	0	8	2	0
0.01 c.c.—Positive	7	0	5	0	0
%Positive	5	0	7	0	0
0.001 c.c.—Positive	5	0	2	0	0
%Positive	3	0	3	0	0

* To August 12.

Use of Plant Effluent in the Park

The effluent under discussion is being used to supply Metson Lake and Chain of Lakes in combination with water released from Stow Lake. Elk Lake was created in 1936 and Mallard Lake is now under construction, both to be supplied wholly with plant effluent.

Metson Lake has an area of somewhat over an acre and a holding capacity of possibly two million gallons.

From Metson Lake to South Lake, of Chain of Lakes, an artificial brook about two-thirds of a mile in length, with numerous cascades and waterfalls, has been constructed to convey the combined flow of effluent and of water from Stow Lake. The stadium, which can boast of one

of the finest polo fields in existence, is irrigated with plant effluent conveyed in a pipe line under pressure and applied by means of hose, with and without sprinklers. At times and places, temporary irrigation ditches, with laterals, are employed to irrigate dry areas.

The sewage effluent is thus employed both for beautification and irrigation in the western half of Golden Gate Park and it is difficult to separate one use from the other or determine which is the more significant.

Proposed Further Development of Salvaged Sewage for the Park

The Board of Park Commissioners has recently granted permission to the Department of Public Works to erect the proposed Richmond-Sunset Sewage Treatment Plant within the park boundaries. The site mutually agreed upon comprises several acres of land north and northeast of the Murphy Windmill in the extreme southwest corner of the park. In consideration of this privilege involving lands of great value, the Department of Public Works, when the funds become available, will undertake to supply in perpetuity three million gallons per day of sewage treated to conform in quality with the rigorous requirements of park use. In addition, all sludge produced at the proposed plant will be digested or otherwise rendered innocuous, dried to an acceptable degree of moisture and ground to a consistency suitable for employment as a fertilizer in the parks under the jurisdiction of the Park Commission.

Acknowledgments

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SUPERVISION OF SEWAGE WORKS OPERATION BY THE ENGINEER OF DESIGN *

By G. A. Parkes

Asst. Engineer, Div. of San. Engineering, Los Angeles

As a unit of the public works system of an average community, the sewage treatment plant differs radically from most engineering structures. In addition to performing a function in which the citizen and taxpayer has little active interest, it depends more upon proper operation for success in fulfilling the purpose for which it was designed, than any other municipal unit. Many a poorly designed plant has been made to perform satisfactorily by skillful and conscientious operation, and many a well-designed plant has failed completely because those in authority have not insisted upon and provided for adequate operation.

A sewage treatment plant is invariably planned and constructed to meet some definite need; to remedy some existing or expected condition. It is rarely intended to be a thing of esthetic beauty or of civic pride, such as a war memorial or a municipal auditorium. Whether the plant is planned and constructed as a part of a complete new sewerage system, or as an addition to an existing system, it is intended to prevent or eliminate a condition which constitutes a nuisance or a menace to health, or both. Such plants are often built only after years of recommendation by health authorities, protests by citizens, and injunctions by corporations and adjacent communities which have made such action imperative.

The construction of a sewage treatment plant is often financed in some manner, such as a bond issue, only after an extensive educational campaign, in which the voters are convinced of the pressing need for such an improvement. It is strange, but unfortunately frequently true, that the all-important need of continued operation of the treatment plant is often overlooked.

Unlike most other municipal structures such as bridges and roads, which, with a small amount of maintenance, passively perform their functions, the sewage treatment plant is an active thing, requiring regular and intelligent care if it is to do the work for which it is intended. The modern sewage treatment plant is highly mechanized and in addition utilizes intricate biological processes, all of which must be closely watched and carefully controlled. Such a plant is a marvelous combination of ingenious mechanical devices and applied natural forces, which, while more or less automatic insofar as the processes themselves are concerned, cannot be neglected or carelessly handled if satisfactory results are to be obtained. Like many other forces of nature, those used in sewage treatment may have disastrous results when allowed to run wild. The conditions resulting from the neglect

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of a sewage treatment plant may easily be worse than if the plant had never been built.

Sanitary engineers and health authorities have long been aware of these facts and it has been largely through their efforts that better plants have been built and that more attention has been paid to the operation of all plants. Recently it has been suggested that the engineers who design the plant be charged with its supervision and operation, on the assumption that they are best qualified to determine whether it is being operated to best advantage. This policy is being successfully carried out in a number of instances and it is the purpose of this paper to review briefly the present general practice in regard to operation, the advantages of the new policy and to suggest possible means by which it may be carried out.

The whole problem of treatment plant operation resolves itself into four general phases—new plants, old plants, plants serving small communities, and large plants serving cities of considerable size. For purposes of discussion the problem of the new plant in the smaller community will be considered first, as the factors involved often apply also to larger plants.

The sewage treatment plant is usually built long after the need for it has been known. In the smaller communities, the city engineering force seldom has available a sanitary engineer capable of designing the new plant. A competent consulting engineer is usually retained to study the problem and to submit a report and estimate on the project. The preparation of this report involves a careful study of all the conditions, particularly those surrounding the point of final disposal of the effluent. Probably over ninety-five per cent of the sewage produced in this country finds its way directly or indirectly into some body of water, a river, lake, estuary or ocean, and it is a well-known fact that the natural processes of purification will enable these bodies of water to receive and dispose of certain amounts of organic and bacterial pollution. The engineer must determine what portion of the organic matter and bacteria in the sewage must be removed by the treatment plant in order to prevent overloading the natural processes of the receiving body of water. He then selects the type of treatment process best suited to achieve this end and determines the size, general arrangement and approximate cost of a plant to incorporate all the various units which he believes will be required. In making these plans, he must naturally assume that provision will be made for operation of the plant.

If the community can raise the necessary funds, the engineer then prepares final plans, specifications and frequently supervises construction of the new plant. In the final designs, the matter of operation is even more closely kept in mind. Every unit in the plant, every piece of equipment, every pipe and valve, is carefully selected on the basis of expected satisfactory operation. Certain types of pumps, for instance, satisfactory in other services, are not used in sewage plants, because they will not operate on the material to be handled. Certain types of

equipment must be specially designed for use on sewage, where ordinary equipment would fail in operation. The competent designer has made it his business to know these things. He has spent years of study, observation and actual experience in accumulating this knowledge and he designs the plant accordingly. But no matter how carefully he may design or how trouble-free he hopes the plant will be, he knows that in the final analysis, success or failure will lie in the operation of the plant after it is put into service.

And here we come to the real crux of the whole matter—the human element. Just as design depends on the designer, the man; so does operation depend on the operator, the man.

The qualifications of a competent sewage plant designer are high. He must have at least a working knowledge of many subjects not ordinarily required of engineers in municipal work, in addition to the specialized subject of sewage treatment. His knowledge must include at least the fundamentals of such subjects as electricity, chemistry, biology, mechanics, structural engineering, thermo-dynamics, hydraulics, architecture, landscaping, construction, civil engineering, and many other branches of engineering science. He must also understand financing and budgets, some of the fundamentals of law and salesmanship, and should be able to handle men and administer projects. He must also thoroughly understand the practical field operation of sewage treatment plants and be able to diagnose operating troubles and devise remedial measures.

These are the qualifications of the good designer and the municipality expects to get such a man, or group of men, when it retains the services of a consulting sanitary engineer. The engineer, therefore, is qualified to design the plant and certainly no one is better qualified than he to say how the plant should be operated.

Too often, however, the municipal authorities, failing to realize the importance of efficient operation, assign a man to sewage plant operation who is in no way fitted for the job. It is true that first class, experienced sewage plant operators are not easily obtained. It is rare that the authorities are far-sighted enough to offer a salary sufficient to attract an experienced operator from some other city, and it is only in the large cities, having existing plants, that an experienced man can be transferred to take charge of a new plant. But there is no excuse in any community for placing a man in charge of a plant, who is also expected to be a part-time street sweeper, city hall janitor and the whole staff of the sewer maintenance department. Nor is there any justification whatever for making the appointment only on a political basis. A man who is already overloaded with work or whose only qualification for the job is that he "knows the right party," is not likely to take much interest in the proper operation of sewage treatment plant or to spend the long hours of hard work which will probably be required of him.

As sewage plants vary in size, type, and individual design to such an extent that no two are exactly alike, it is difficult to state exactly

the number of men required to operate any plant, but it may be safely said that in general, sewage treatment plants are under-manned and that the operator or operators are expected to do more than should reasonably be expected of them. This is particularly true of the smaller plants.

In any case, the qualifications for a good operator, lacking previous experience in such work, should be somewhat as follows: He should first of all be conscientious and reliable, willing to work as long and as hard as need be to keep his plant in good condition, both as to efficient operation and as to general appearance. In short, he should be a man who will realize that he has an important job to do and who will take a pride in doing it well. He should have a fair education, preferably a high school graduate, although many men with only grammar school educations have become excellent operators of small plants. In recent years a number of college men have gone into sewage plant work and have become splendid operators. These men have found the work congenial and worthy of the best efforts of their scientifically trained minds. Some of the superintendents of the larger plants receive good salaries.

The average plant operator should have considerable mechanical ability, as most of the plant troubles are of a mechanical nature. He should also have practical knowledge of electricity, pipe fitting, carpentry, gardening, etc. He should be able to keep records and to make the simple chemical tests essential to proper operating control. All in all, he should be a general handy man, always ready to learn, ready to meet emergencies and to make a good impression on visitors.

There are many such men available in any community and the municipal authorities should see to it that such a man is placed in charge of the sewage treatment plant. It is also the duty of the designing engineer to sell this idea to the authorities and to insist that he be permitted to select the operator or operators.

But no matter how competent a man is selected, it is not reasonable that he be expected to place a new plant in operation and control the intricate processes without instruction; here is where the expert supervision of the designing engineer is essential. The latter must act as instructor, explaining how each unit and piece of equipment is supposed to operate. He must give to the operator an elementary course in sanitary engineering, so that he (the operator) may intelligently solve the problems which are certain to arise. Someone from the engineer's force should be able to instruct the operator in the making of required chemical tests and to explain their significance.

Obviously it is impossible for any man to absorb all this information in a short time, particularly one who has had no previous experience in such work. Furthermore, sewage plants take anywhere from three months to a year to "break in" and to develop an operating routine. No sewage plant yet constructed, no matter how carefully designed, has failed to develop "bugs" during its early period of operation. These operating difficulties must be eliminated and here

the experience of the designer is invaluable. His recommendations will result in restored operation at a minimum of expense and delay and his knowledge of plant operation will enable him to determine whether the plant is operating at its rated efficiency and is meeting the requirements for which it was originally intended.

But continued supervision of the plant operation would require the expenditure of a very considerable amount of time on the part of the designing engineer, and it is unreasonable to expect him to do so at his own cost, unless an arrangement had been made to include the cost of such supervision in his original fee. It is suggested that some arrangement be made whereby the consulting engineer be retained in the usual way for the preparation of the plans and that an additional retainer be arranged, to cover the cost of supervision for a stated period, say one year. This arrangement could easily be worked out to fit any individual case, and would depend upon the size and type of plant and other factors. In cases where the plant receives heavy seasonal industrial loads, it might be desirable to extend the supervision period for a longer time.

The advantages to both parties of such an arrangement are obvious. The community obtains the advisory services of those best qualified to supervise operation of the plant, thereby insuring satisfactory results and a protection of its investment, while the consulting engineer is able to insure that the plant is operated as he intended it to be and avoids possible criticism in case the plant fails through faulty operation. A noteworthy example of this arrangement is in connection with the new treatment plant at Buffalo, N. Y., where Greeley and Hansen have been retained to operate the plant for the first year of operation.

In the case of older plants now operating in the smaller communities, the operator has probably already received a certain amount of instruction, either from the designer or from others. He has probably solved most of the operating troubles and has settled down to a more or less satisfactory operating routine. If there have been no complaints regarding the sewage disposal arrangements, the authorities probably feel that everything is satisfactory and nothing further is needed. However, this may not be true, and it might well pay the community to again call in the engineer who designed the plant and request him to make a survey of conditions and to make recommendations for improvements, if such are needed. It might easily prove to be the case that the operator had become careless and has not been operating the plant as efficiently as possible. Also, recent developments in plant arrangement may have come about, which could be incorporated into the existing plant, with a resulting improvement in efficiency or a lowered operating cost.

The cost of such a survey would not be great and might easily be offset by operating economies or possible revenues. In any case, the municipality would have the satisfaction of knowing that its sewage plant was being properly operated and that the city was still getting its money's worth.

In the case of the larger cities, much that has already been said still obtains. Frequently, an outside consulting sanitary engineer is retained to prepare the plans for new sewage treatment plants. The arrangements between the engineer and city as regards the supervision of operation of the plant may readily be the same as in the case of the smaller city, allowance being made for the fact that skilled personnel is more often available. Certainly, it is proper that the designing engineer be permitted to assist in the supervision of the early stages of operation and to make recommendations, if not actually give orders to the operating staff. He should be permitted to assist in the selection of the operators and supervise the collection of operating data. Just how long the consulting engineer should be retained in this supervisional capacity and what authority he should have, would depend on the circumstances of each case, but it is the opinion of the writer that the conditions differ only in degree from those of the smaller plants. The arrangement for such supervision should at least extend for a period sufficient to demonstrate the success or failure of the new plant. Again the writer wishes to emphasize the point that if the engineer is competent to design, he is also best qualified to supervise operation and the cost of such supervision is a price which the city can well afford to pay.

And last but by no means least, this discussion comes to the case of the large city with a staff of engineers well qualified to design a sewage treatment plant. Such a staff usually consists of a group of specialists, such as mechanical engineers, structural engineers, etc., all working under the direction of one or more competent sanitary engineers. It sometimes happens that the city already has one or more existing plants which have been designed by this staff.

The design of a new plant for a large city presents some difficulties not encountered in the design of a small plant. Local conditions, such as difficulties of obtaining a suitable site for the treatment and disposal of a large volume of sewage often affect design, while the necessity of keeping unit costs of construction and operation to a minimum always enters into decisions as to type of plant and processes to be used. The steps which must be followed in the design of a large plant are essentially the same as for a small one, except that each decision is reached more carefully, because of the great cost involved, and the plans proceed to completion more slowly on account of the tremendous amount of interrelated detail which must be worked out. But throughout the whole process of the design of a new plant, large or small, the matter of operation must be kept in mind. Often a decision of importance may hinge on whether a certain arrangement of piping, or an electrical circuit, or a mechanical device can be operated efficiently and conveniently. In fact the comfort and convenience of the operators themselves is often given more consideration than the latter are inclined to believe.

A sewage plant so designed is usually well-designed, adequate in size, up-to-date in theory, and practical in application. It will prob-

ably, without major change or alteration, serve its purpose well, and protect the comfort and health of the community for many years, providing—it is properly operated.

At this point, the writer begs leave to digress for a moment.

Sewers are as old as civilization, sewage treatment is relatively new. Sewers were apparently used in Nineveh and Minos, but sewage treatment began at about the turn of the century, while sewage treatment as we know it today, dates back hardly more than a decade.

The science of sewage treatment is today undergoing such a period of rapid development and improvement as to place it on a par with radio and air transportation as a fast moving science. Many of the brightest scientific and engineering minds are at work upon the problems of sewage treatment and studying the phenomena connected therewith. The sewage plant designer of today must constantly keep himself in touch with the latest developments both as to design and operation in order that his plants may not become obsolete almost before they are completed.

This rapid development and the types of plants it is producing, requires an entirely new attitude toward the operation of such plants.

In the old days of sewage treatment, the plant when constructed, was usually turned over to who ever had charge of the sewer system itself. This individual, who usually knew nothing of the technicalities of the subject and cared less, generally neglected the plant or gave it scant supervision. The limitations of the early septic tanks and sewage farms, as efficient treatment works, are now well-known, although it is not likely that the negligent operation they received (or didn't receive) improved their reputations.

Even in later years, the sewage treatment plant has customarily been placed under the supervision of those in charge of sewer maintenance. While this practice may, or may not, have had satisfactory results in the older types of plants, it is not likely to be successful in the plants of today or tomorrow.

No criticism is being made, or even inferred, of the splendid work done by the sewer maintenance superintendents and their forces, but the maintenance of a large system of sewers is a "man-sized" job in itself, leaving little time for study into the highly technical subject of sewage treatment.

The design of a sewage treatment plant is also a "man-sized" job, but in the modern plant, design and operation are so closely related, that the writer predicts that in the future all new plants will be operated under the supervision of the designing engineers.

There is nothing new about such a policy, it having been in force in one form or another, in a number of cities for many years, with very satisfactory results. The advantages are so obvious and the disadvantages so few, that it seems likely to become more or less universal within a few years.

As to the advantages of placing existing plants in large cities under the supervision of the designing engineers, where such plants are not

already so controlled, the writer feels that each case must be judged on its own merits. Some plants are so obsolete and run down that little improvement is possible and a new plant is probably necessary. Other plants are so splendidly operated that change in supervision could not possibly make them any better. In general, however, it is believed that most existing plants would be benefitted by being placed under the supervision of competent sanitary engineers for the reasons already stated.

There is one more item, which may not rightly belong in the discussion but which has a direct bearing on plant operation. No sewage treatment plant, or any other plant, for that matter, can be operated without money. It is likely that an inadequate operating budget has caused more plants to fail than any other cause; human, biological, or mechanical. The saying, "the laborer is worthy of his hire" is more truthful than poetical in the case of the sewage plant operator. Many a city administration, anxious to make a good financial showing, has failed to see to it that sufficient funds are provided for plant operation. Sanitary engineers should make it their duties to see that adequate funds are provided for operation of the plants for which they are responsible.

The close connection between the operator and the designer has another decided advantage. The last sewage plant has not yet been designed and built. Plants for the disposal of municipal wastes will be built as long as cities exist and hundreds or even thousands of new plants will be required in the future. If improved treatment processes are to be devised and better plants built, such improvements can only come from close observation of existing plants. Past mistakes can only be remedied or avoided if their underlying causes and results are thoroughly understood.

Occasional visits to the existing plant or the obtaining of information second-hand from non-technical persons, is not sufficient for such understanding, and, opportunity for such observation and study can best be had if the designer has actual supervision of and responsibility of the operation.

May the writer close this discussion with the plea, that hereafter the ancient feud between the "white collared man" and the "working man" be forgotten—that the engineer take it upon himself to learn the operator's point of view—to work with him in dirty overalls if need be —and give the operator in a friendly, kindly way the benefits of his own wider technical experience. And—that the operator, cooperating with the engineer, accept gratefully what is offered, and give in return from his hard-earned store of practical knowledge.

After all—designers and operators—we are all out to do the same job.

Industrial Wastes

CEDAR RAPIDS' AGREEMENT WITH THE PACKERS *

By Howard R. Green

Consulting Engineer, Cedar Rapids, Iowa

Cedar Rapids was the first city in Iowa to undertake sewage treatment on an all-inclusive basis. That is, it was the first municipality of size to recognize and accept both the domestic and industrial wastes as a responsibility of the Public Health Department and further to develop and operate a single installation adequate to process all pollutional material produced within the district and financed on an equitable basis acceptable alike to the public and the industries.

There appear to be valid reasons in favor of this sort of solution of the stream pollution problem.

1. It places the entire responsibility of final results on the shoulders of the city government.
2. The City Council is by statute named as the local board of health and is clothed with all necessary authority and financing machinery to carry out the assignment.
3. The cost of construction and operation is materially lower in the case of a combined plant than would be the case with several individual plants.
4. Financing terms available to municipalities are usually much more favorable than to industries, and
5. Individual concerns are relieved of a troublesome operating detail and considerable cost.

That the arrangement is working well is a source of gratification to all who had a part in its development. It did not drop from a clear sky. It was the result of several years of preparatory work and a great deal of cooperative effort. That the result was hardly hoped for even by the State authorities is indicated by the fact that when the State Department of Health and the Executive Council served notice on the community that a clean-up of the river was in order, separate notices were served upon the city and the various contributors of trade wastes.

In the preliminary engineering investigation it was early determined that probably it would cost all concerned less to combine their problems than to attempt to solve each separately. The first stumbling block was the lack of an equitable means of financing. There was no legal background for a system of charges which might vary from year to year in proportion to service rendered. The only available methods provided by statute to meet construction costs were by bond issues

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based upon either special assessments against benefited property, or ad valorem taxes against all property. Operation and maintenance costs could be met by ad valorem taxes only.

The special assessment method was considered impractical because of the ponderous procedure required by the law, the short (10 year) financing period allowed, and the obvious future inequalities as properties which were unbenefited at the time of the levy later became beneficiaries at no appreciable cost. Likewise the millage levy tax method could not be made equitable as the money contributions of properties of equal value would be identical regardless of the occupancy or demand for service. Under this plan a $100,000 storage warehouse producing no sewage would pay equally with a cannery of similar value, or a $1,000,000 dry milling concern, demanding little or no service, would be taxed on a par with a wet process plant of equal assessed value.

So a sewer rental law was prepared. It was modelled somewhat after the Ohio statute, and while drawn particularly to provide a basis for Cedar Rapids financing, its general language made it applicable to all cities and towns in the State. It has since been used by many. It was sponsored by local legislators at the next session and passed both houses without an objection or a change in its original form. One reason that the bill passed without opposition was that it did not open the door to any increased municipal obligations; it did not provide for any new form of bonds or any increase in the statutory limit of indebtedness; nor did it resort to the subterfuge of authorizing the issuance of apparent obligations which were not backed by the full faith and credit of the city, the so-called revenue type of bond. It merely provided an optional method of retiring the interest and principal of bonds already authorized. It provided that when a city, by ordinance, had created a sewer district and had built, or had undertaken to build, sanitary works including mains, interceptors and treatment plants, and had issued bonds backed by a millage levy running against all the taxable property within the corporation as already provided by law, it might then by ordinance institute sewer rentals to be used to pay all or any part of the cost of financing the construction and operation of such works, and such rentals so applied would automatically displace and make unnecessary a similar amount of ad valorem taxes. But these taxes, already levied for the entire period of the retirement schedule of the bond issue, would remain in force as a background of security to be used in the event of insufficient funds accruing from rentals, or a repeal of the rental ordinance by any future council. Thus the bond holder was protected, and a bond sale at best current rates was assured; and the tax payer was protected against any increase in the total funded obligations of the city above the constitutional and statutory limits of indebtedness.

When this bill became a law, definite steps were taken toward the design of a plant. Most of the investigational work had been completed. Two tentative plant layouts and detailed estimates of cost were made:

1. For a plant adequate to care for the city at large but exclusive of the requirements of the major industries;
2. A larger plant layout on the basis of caring for all of the wastes of whatever character originating within the city.

The difference in cost between the two plans represented the additional cost caused by industrial wastes, and therefore the amount which it was thought the industries should pay.

PWA had just been established and an immediate application was filed for a 30 per cent grant on the basis of the complete plant. This application was approved as Project No. 1 for the State of Iowa. The grant was approximately $200,000.

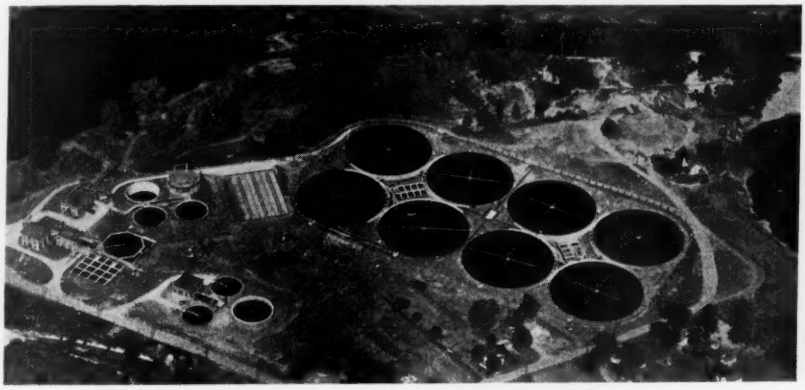
On this basis it appeared that the construction and operating costs of the general city plant could be financed by adding about 25 per cent to the bi-monthly bills of all consumers of city water, if rateable collections were made from minor industries. It was assumed that the consumption of water upon an individual property was a rather definite index of the quantity of sewage produced, and therefore demand upon the purification facilities. Stated in per capita terms such a rental amounts to approximately 90 cents per person, or $2.25 per water consumer, per year. As a matter of comparison, plants so financed in Illinois require $6.59 per consumer per year. This low total rate would be possible only if rateable collections were made from minor industries. There remained the matter of major industries to be disposed of.

Armed with the estimates of cost, the promise of a 30 per cent grant on construction cost, an outline of the proposed rental ordinance, and the representation that ad valorem or millage levy taxes were not to be made, conferences were held with the respective executives. Obviously no opposition developed among dry process operators. Rentals proposed to them on the basis of plant population were extremely moderate as compared with what their tax contributions would have been if computed on a property valuation basis. Of course, all such conferences were based on preliminary estimates. No written commitments were asked for or taken, but it may be stated here that not a single reversal of opinion, or effort to evade, was made when one and one-half years later the collection of rentals started.

Settlement with wet processors was more complicated. Observations of quantity and concentration of waste were made and, generally speaking, rates were computed upon the basis of the volume of sewage produced at the regular city rate multiplied by the ratio of concentration. Thus, the producer of 100,000 gallons per day of 600 B.O.D. waste was asked to pay double the rental applying to the same quantity of general city waste at an estimated 300 B.O.D. It was decided to treat all of the industrial wastes, except those of the meat packing plant, in the general city plant, depending upon the dilution of these miscellaneous trade wastes by the domestic sewage to eliminate or reduce troublesome characteristics. Therefore, the application of the foregoing methods of fixing rentals automatically allocated the costs with

some degree of equity. But these preliminary rate fixing conferences presented clearly the necessity of a very flexible rental ordinance which would permit either flat, volumetric or concentration rates as each case demanded.

At this point it must be remarked that we were dealing with PWA and, of course, a dead line for awarding contracts was set. Obviously a settlement of all financing and rental details could not be concluded within the time allotted. It must be remembered also that the State Department of Health had issued a separate order to the packers, and they had their option of building a separate plant, or if the city were willing, of joining with the municipality. Preliminary estimates indicated that if the city plant were enlarged to care for the packers, an additional expenditure in excess of $200,000 would be required. The 30 per cent grant would reduce this to about $140,000. The city was willing to undertake the project if the packers would reimburse it in like amount, and provided the packers would pay the estimated addi-



Airplane View of the Cedar Rapids Treatment Works.

tional operating costs involved by reason of the inclusion of their wastes. If the packers could do better by themselves, certainly they should be encouraged to handle their problem individually. To decide this point took time; and time was not available without jeopardizing very substantial federal aid.

By this time the general design of the city plant had been determined. It was to be of separate sludge digestion type with circular trickling filters and a battery of final clarifiers. The presence or absence of packing wastes did not alter this portion of the design except as to size. Therefore, a chance was taken. The filters were proportioned to care for the packing wastes, and plans were completed for eight one-half acre trickling filters, each 167 ft. in diameter, and a contract was awarded. The contract sum of $220,000 against a preliminary estimate for this department of the work of $260,000 gave hope and some confidence to all concerned that other items of the preliminary estimate might be depended upon as maximum.

All plant units were designed to accommodate peak rates of flow, at least 17 per cent in excess of those determined by gaging current maximum requirements. This was the estimated provision for ten years' population growth. Of course, the pump station, pipe lines, etc. were designed for a much larger excess capacity on the basis of 40 years expected population growth. The application of sewer rentals tends to reduce the total quantity of flow because individual property owners divert all possible clear water wastes to the storm sewer system in an effort to reduce their rentals. This attitude has been encouraged by the city. The result is an additional factor of safety in plant capacity, but of course reduces the total rental income somewhat below preliminary forecasts. When a substantial portion of water consumed on a property is not polluted and is not drained to the sanitary sewers, separate meters are used. In some cases where such an arrangement is impractical, flat rates have been arranged. Private water supplies are either metered or covered by special contract based on quantity of production. In the case of wholesale consumers, the city water rate drops so low that 25 per cent would hardly cover the disposal plant operation, so the ordinance contains a provision that in no case shall the sewer rental charge be less than three and one-half cents per thousand gallons.

The maximum rate of flow of city sewage (except for temporary peaks caused by rainfall) was set at ten million gallons per day as of 1943. The maximum B.O.D. of city waste sustained for a four-hour period, which coincided with the maximum rate of flow, was 400 p.p.m. The maximum rate of delivery of packing wastes to the plant was estimated at 3.4 m.g.d. By the use of a 500,000 gallon storage reservoir it was proposed to reduce this maximum to a constant delivery rate of 1000 g.p.m. and to operate at this rate for from 18 to 24 hours per day as necessary. If the capacity of the storage reservoir proved to be inadequate to iron out the extreme peak rates, then the surplus or overflow would be returned to mix directly with the incoming city sewage and pass through the general city plant.

It was hoped that by grease removal and fine screening at the packing plant, followed by mixing in the storage tank and constant operation of a flocculator and two stages of clarification, to reduce the peak four hour B.O.D. of packing waste from 3300 to 1700 before mixing with clarified city sewage and applying to the trickling filters, followed by final clarifiers. This it was thought should produce an effluent B.O.D. of 100 or less. The dilution factor offered by the Cedar River (which flows at more than 800 c.f.s. ninety per cent of the time) would be adequate to care for the problem from this point on.

As a matter of fact, in 1936, 7.3 million gallons of sewage per day was reduced from an average B.O.D. of 422 to 62 (85.3 per cent). It was predicted that the B.O.D. of packinghouse waste combined with city sewage on a 1943 basis would be 39,000 lbs. per day. In 1936 it ran 25,569. The treatment was expected to reduce this demand to 4000 lbs. per day before discharging into the river. In 1936 the average

demand of effluent was 3751 lbs. The dissolved oxygen in the river water, at minimum rate of flow of 650 c.f.s. and allowing only 4 p.p.m. of dissolved oxygen, is 14,000 lbs. per day. Therefore, under the worst conceivable river conditions the effluent in no way depletes the oxygen supply.

Unqualified cooperation of the officials of the Wilson Company was had throughout the entire program. Access to the plant operations was freely given and the original investigation was supplemented by studies of various methods of pre-treatment. Roughing filters, rapid sand filters, and chemical precipitation were studied. Sand filters were abandoned because of the relatively short cycles of operation secured, even after primary clarification, and the amount of attention required by this process was found to be considerable. The roughing filters were abandoned because of a fear of operating costs and difficulties. It was deemed better judgment to use chemicals to assist in the process rather than as antidote to the process (as required in odor control).

Primary sedimentation followed by flocculation and a second stage of sedimentation was decided upon as adequate in this case, and the plant was arranged to provide maximum flexibility so that flocculation could precede the operation of the clarifiers in parallel. It was early determined that the cost of coagulants could be kept below $8 per million gallons under the loading conditions which it was anticipated must be met. It was kept in mind, however, that as a protection against future increases in loading the same mechanical equipment might be used and the quantities of coagulants increased, if necessary, to produce a relatively constant degree of clarification. It should be stated here that the theory of the pre-treatment plant was that its function should be to prepare the packing wastes for application to the trickling filters so that the same would not become clogged, and that whatever reduction in B.O.D. was secured by this pre-treatment process, should be considered as incidental.

In the early conferences with the packers, the following figures were presented:

1. The extra cost to the city for all additional units and capacities by reason of including the packing wastes would be approximately $216,000.
2. A 30 per cent grant, which could be secured by the city but not by the packers, would have the effect of reducing this difference to $151,000.
3. An individual plant to accommodate the packing house wastes only and to secure the anticipated results would cost approximately $309,000.

This was important money and naturally the officials hesitated. The 2:1 cost ratio smacked of a promotional effort to stampede them into a transaction which they might regret later. Also there was the ever present suspicion that when one deals with a city or other political

sub-division, influences other than business judgment enter the deliberation. But against the agreement that their cost under city jurisdiction would be limited to $150,000, the following queries had to be answered:

1. Could they build the same sort of plant for less money?
2. Could they operate an individual plant for less than their proportional cost of operating the city plant?
3. Could they build a less extensive plant and satisfy Department of Health requirements?
4. Did they wish to assume the responsibility of operating a plant?
5. Did they wish to run the risk of having to extend an individual plant in case their first structures did not meet requirements?
6. Assuming that it really did cost more money to deal with the city, what was it worth to them to get rid of the whole problem once and for all for a known cost?

All these questions were perfectly natural and in line with the process of analysis which a good business man would use in considering a large investment—an unwanted investment in plant facilities which added nothing to the value of his product, and in fact, reduced his previous net earnings. After a year of investigation, conferences and debates the decision was made. It was to join with the city and pay a rateable proportion of the construction and operating cost. A preliminary contract was entered into which was to be followed by a final agreement when the actual costs became known.

A digest of the first contract is as follows: It recited

1. That the company owned and operated a meat packing plant in the city which produced industrial waste,
2. That the city was constructing a sewage disposal plant adequate to treat all the wastes produced within the city,
3. That the city proposed to finance said works by equitable sewer rentals,
4. That the company's demands for such service represented a substantial proportion of the total cost of such works,
5. That, therefore, a special contract became desirable and it was agreed:

    A. That the city provide for the company's demands for a period of twenty years,
    B. That the city should finance both construction and operation of the plant,
    C. That the city should enact a proper rate ordinance,
    D. That the company permit the city to build sewers and pumping stations on company land,
    E. That the company maintain and operate grease removal and fine screening units in its sewer lines prior to discharging the liquid into the city-built sewers,

F. That the decision as to the percentage of cost of both construction and operation should be made by the designing engineer, and that his allocation of costs be accepted by both parties,

G. That the company enter into a final agreement on such basis and pay the costs so determined over a twenty year period,

H. That the responsibility as to the adequacy of the system of treatment rest with the city.

With the execution of this document the designing engineers were handed a neat assignment. From this point on they had two clients. They must serve both with equal conscience. To be fair to the city the plant must be adequate to serve the anticipated needs of the company for the twenty year duration of the contract, lest the city, at its own cost, have to expand the treatment facilities. On the other hand, the provision for packing wastes should be no more extensive than necessary, and the completed outlay required must be kept below $150,000, if at all possible. It is obvious that the engineers' report on an equitable division of the cost had to be on a defensible basis.

However, the feeling between the city, its inhabitants and its industries is normally cordial, and the harmonious final settlement was due fully as much to this influence as to any judicial efforts on the part of the engineers.

The construction costs were finally divided as follows: The company installed grease removal and fine screen units at its own cost and on its own property. These units, under normal market conditions for grease and tankage, not only carry their costs but show a net return. The company was asked to pay the full cost of construction of sewers to serve its various plant units; for an automatic pumping station; for a pressure line to the city plant; for a storage reservoir and two clarifiers; and for a completely equipped control building, including a rate of flow controller, a flash mixer, a flocculator, chemical storage tanks and chemical dosing equipment. The general plant unit costs were divided in substantial proportion to the estimated demand made upon each by the company wastes. For example, twelve per cent of the filters and final clarifiers, twenty-one per cent of the outside pipe lines, seven per cent of the primary clarifiers, fifty-three per cent of digestion tanks and equipment, fifty-three per cent of vacuum sludge filters and about eight per cent of miscellaneous plant costs. The company was asked to pay nothing toward the city pump station, the gas engine generator set, the city screen and incinerator station, etc. The final total cost allocated to the company was $137,000.

The final contract provided that the company pay this amount to the city in twenty annual equal installments at $6850 per year plus interest on deferred balances at the rate of four per cent per annum. These terms were parallel to the city's own financing requirements. The annual payments are made on December 1 of each year regardless of the

operation of the packing plant. The largest annual payment on this account is $12,506 and the smallest is $7124.

Thus if future event such as fire, labor difficulties, conversion of the packing plant to other uses, sale of the property, or government regulation of meat production, close the plant to its present uses, the remaining obligations for original capital expenditure would remain as a lien against the property.

In addition to these capital charges, the company agrees to pay in monthly installments $4000 per year toward plant operation costs during any year in which any livestock is butchered or processed in its plant. The company also agrees to discharge condenser water into the sewer lines as requested by the disposal plant operator for the purpose of sewage dilution or increasing the temperatures of plant processes. But should the city desert the sewer rental plan during the life of the contract, or levy any ad valorem tax for sewage disposal purposes, such amount as is so collected from the company or its successors shall be deducted from the agreed total rentals provided.

The foregoing plan has worked admirably. It can be made to work elsewhere where conditions are similar, provided the political body and the industry can work together on a business basis. The hazard so far as equity is concerned is in the lack of definite preliminary information as to the actual demands of the industry. Try as he will, the designing engineer is apt to be too conservative in estimating certain demands and too optimistic as to others. These elements have a direct bearing on the cost and its allocation, and twenty years is a long time to continue unfair payments. The question may be asked then "Why make a twenty year contract?" The answer is that no right-minded executive will enter into any agreement which is subject in any appreciable degree to the whims of changing city councils or district trustees. He has been taught to tolerate government control but he does not invite it.

PACKINGHOUSE WASTE AND SEWAGE TREATMENT AT SIOUX FALLS, SOUTH DAKOTA *

By R. E. Bragstad and Leland Bradney

City Engineer and Plant Chemist, Sioux Falls, South Dakota

Before going into the matter of packinghouse waste, it is probably advisable to outline briefly the general problem and types of treatment afforded at the Sioux Falls Sewage Treatment Plant, which treats combined domestic and packinghouse wastes.

The City of Sioux Falls has a population of approximately 35,000 persons, 90 per cent of whom are connected to the sanitary sewers. The domestic sewage from the business district is from combined sewers, whereas that from the residential sections is from a separate system. The industrial waste from the meat packing industry and stockyards, with a poulation equivalent of 103,000, constitutes a major part of the organic load that must be handled. It is this waste that makes this problem an unusual one, and it is with this waste that we will chiefly interest ourselves in this paper as it is largely responsible for operating difficulties that have been experienced .

The original treatment plant, constructed in 1927, was designed for the purpose of eliminating a nuisance condition in the Big Sioux River. It was of the separate sludge digestion type, consisting of grit chambers, primary clarifiers, digesters, trickling filters and sludge drying beds. The plant was designed to treat domestic sewage and packinghouse wastes, the packing industry waste being pre-treated by fine screening and short-period settling. It was expected to provide adequate treatment of this material for a period of ten years.

The plant was put into operation in the fall of 1927 and with the exception of minor difficulties it functioned satisfactorily until the summer of 1931. The over-all removals of B.O.D. and suspended solids were from 80 to 85 per cent. The residual 5 day B.O.D. in the plant effluent was still appreciable, varying from 60 p.p.m. during peak filter efficiency in the summer to 175 p.p.m. in the winter.

Because of the low flow in the river it became evident by the fall of 1931 that additional treatment was necessary, not only because of the high residual B.O.D. but also because of increased activity of the packing industry which would further increase the organic load.

In the summer of 1932, an experimental plant was installed and further methods of treatment studied. As a result it was eventually decided to provide for chemical treatment of the packinghouse waste and to supplement the trickling filter treatment by the activated sludge process.

The experimental plant results indicated that the packinghouse waste was amenable to chemical treatment and that a more sparkling

* Presented at the Tenth Annual Meeting of the Central States Sewage Works Association, St. Paul, Minn., Oct. 21, 1937.

SEWAGE TREATMENT PLANT, SIOUX FALLS, SOUTH DAKOTA.

effluent, of lower B.O.D., could be obtained by following trickling filter treatment with the aeration tanks rather than the customary practice of pre-aeration ahead of the filters. Accordingly, the design of the plant additions allowed for operating the filters ahead of or behind the aeration units. However, an indication of possible difficulty was forecast by these experiments as floating sludge was present at times. But inasmuch as conditions never became critical and as it was found comparatively simple to skim the sludge from the very small test unit, an investigation of causes of the floating of sludge in the final tanks was not made. As a precaution, however, final clarifier skimmers were provided for in the design of the plant additions.

The plant additions which were put into operation in the spring of 1936 consisted of a chemical storage tank and solution type of feeders, a flocculator, an aeration tank of the spiral-flow type, two Dorr final clarifiers, three air blowers with auxiliary equipment and necessary pumps for pumping the trickling filter effluent to the aeration tanks, and for returning and wasting activated sludge.

This plant as it now stands is unique inasmuch as it combines three standard methods of treatment in one plane, viz.; chemical treatment, trickling filters, and activated sludge. It is quite flexible, allowing various combinations of these treatment schemes. A flow diagram is shown in Fig. 1.

When the plant was first put into operation an abnormal condition existed, because of flooding of the pump station at the packinghouse waste pre-treatment plant due to high water in the river, resulting in the packinghouse flow being temporarily by-passed. Therefore, the activated sludge plant was started with settled domestic sewage. The results during this period were excellent, the plant producing a sparkling effluent of low B.O.D. When the packinghouse flow was returned to the plant it was settled and mixed with the settled domestic sewage and applied to the filters. The filter effluent was then pumped to the aeration unit. Shortly thereafter floating of sludge in the final tanks occurred. It was suspected that nitrification in the filters, with the subsequent de-nitrification and the liberation of nitrogen gas in the final clarifiers, was responsible. In order to reduce this nitrification a portion of the primary effluents was added to the aerator, but this did not entirely relieve the condition. Thereafter all of the primary effluent was added to the aerator. This resulted in bulking of the sludge. At the same time it became black in color and had the garlic-like odor characteristic of activated sludge in poor condition. Even during this period some floating sludge was evident. In the next period, settled domestic sewage was applied to the filters and the filter effluent along with the packinghouse primary effluent was added to the aerator, with the same result as in the previous period. It was then decided to treat the domestic sewage on the trickling filters, allowing the filter effluent to go to the river direct. The packinghouse primary effluent alone was treated in the aeration plant. Here again bulking occurred. It was then decided that it might be of advantage to treat packinghouse

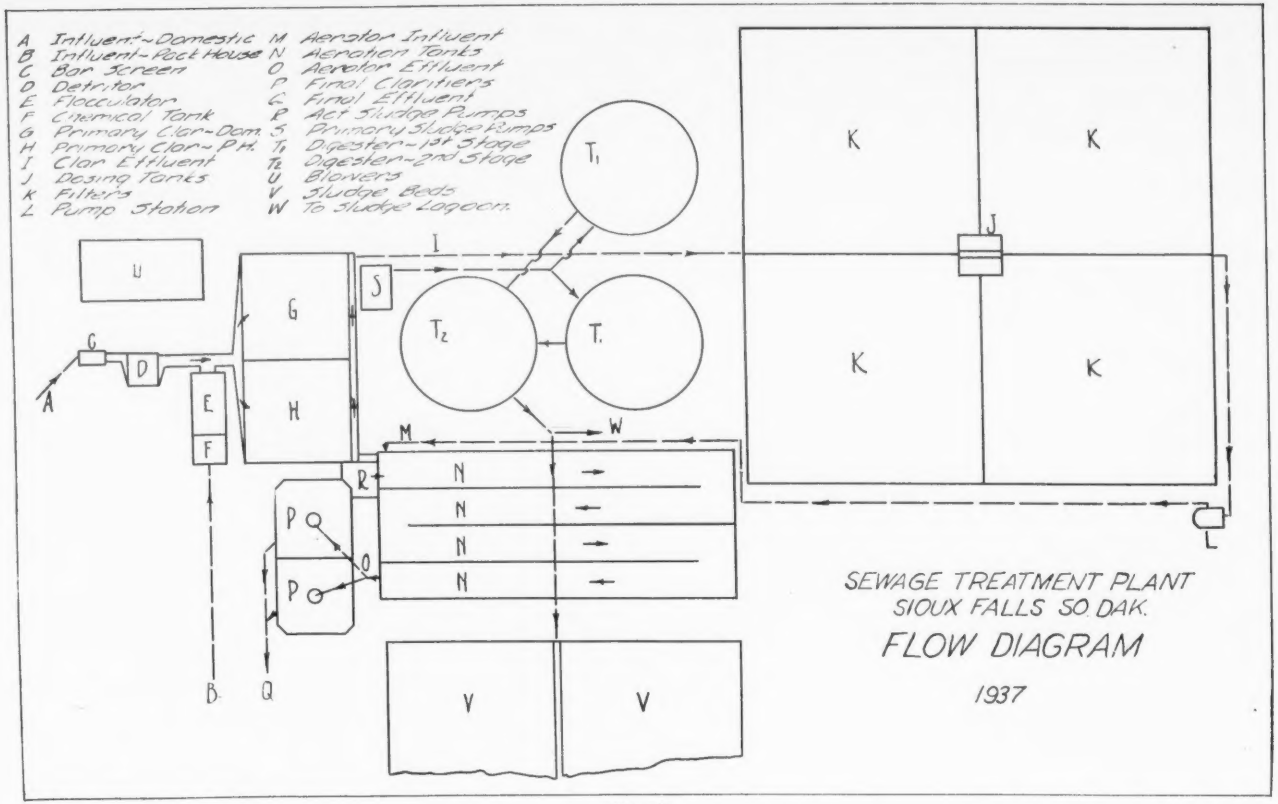

A Influent-Domestic
B Influent-Pact House
C Bar Screen
D Detritor
E Flocculator
F Chemical Tank
G Primary Clar-Dem.
H Primary Clar-P.H.
I Clar Effluent
J Dosing Tanks
K Filters
L Pump Station
M Aerator Influent
N Aeration Tanks
O Aerator Effluent
P Final Clarifiers
Q Final Effluent
R Act Sludge Pumps
S Primary Sludge Pumps
T1 Digester-1st Stage
T2 Digester-2nd Stage
U Blowers
V Sludge Beds
W To Sludge Lagoon
SEWAGE TREATMENT PLANT
SIOUX FALLS SO DAK.
FLOW DIAGRAM
1937

FIG. 1.

waste alone on the filters and the filter effluent combined with settled domestic sewage in the aerators. This necessitated a change in the feed channels of the primary clarifiers. This method was tried for a short period, during which floating was evident at certain times of the day, chiefly the daytime period. Other difficulties encountered were ponding on the filters and odor nuisances at night, due to infrequent dosing. This condition existed even though the doses to the filter beds were made more frequent by reducing the size of the dosing tanks.

The original method of operation was again resorted to, i.e., where both primary effluents were dosed to the filters and the filter effluent treated in the activated sludge plant. A frequent check on dissolved oxygen and nitrites in the aerator and final clarifiers was made and it was noted that floating occurred whenever the aerator effluent was high in nitrites. On the other hand, bulking occurred when the dissolved oxygen disappeared. The point that made control critical was that high nitrites were obtained even at less than 1.0 p.p.m. dissolved oxygen. This made it evident that proper plant control could be obtained only within a very narrow range of air supply and that any slight disturbance or change in the characteristics of the sewage would destroy the delicate balance that had to be maintained at all times.

During all these periods, the digesters were being heavily loaded with solids which could not be properly handled because of the limited sludge drying facilities available. This caused the discharge back to the plant of a supernatant liquor heavily charged with solids and high in B.O.D. This vicious cycle continued until the sludge blanket in the primary clarifiers accumulated at a faster rate than the sludge could be removed to the digesters. The result was a highly septic condition in the one clarifier which received all of the overflow liquor. At times there was as much as one foot of scum in this unit. This condition was reflected back on the subsequent treatment processes. To remedy this situation a plot of land adjacent to the trickling filters was purchased for use as a digested sludge lagoon. While this lagoon has been in use the clarifiers have been kept clear of solids. This greatly aided in the control of solids in the aerator mixed liquor, inasmuch as excess sludge, hitherto difficult to treat, could now be wasted at will to the domestic primary clarifier. This now made it possible to devote more time and study to the aeration process.

In order to insure against a continual re-seeding of undesirable nitrifying organisms by the sludge in the aerators, the mixed liquor discharging from the aerators into the final clarifiers was chlorinated for about a week to the point where the activated sludge was practically sterile and nitrification ceased entirely. Normal operation was then resumed. The plant effluent was extremely turbid and high in B.O.D. for a period of about a week. After two weeks, good clarification was again obtained, but floating sludge again appeared in the final tanks. Frequent tests for dissolved oxygen, nitrites, and nitrates were then run at quarter points in the aerator and the same tendencies as before were noted. The results showed that the nitrites at times ran as high

as 350 p.p.m. very little nitrates being present. By allowing the aerator effluent to stand and determining nitrites and nitrates at intervals it was found that the nitrites were rapidly disappearing without any corresponding increase in nitrate. Examination of the sludge taken from the final tanks during these periods when the sludge was floating revealed that it was enmeshed with tiny bubbles of gas, which, based on the aforementioned facts, indicated that the gas might consist largely of nitrogen. This was further substantiated by collecting this gas and bubbling it through a 0.1 normal solution of sodium hydroxide, the alkaline value of which was only slightly reduced.

The conditions encountered were thus found to be analagous to those occurring at Birmingham, England, as reported by O'Shaughnessy.

It was noted that floating and bulking occurred simultaneously only during the transition from one phase to the other. Ordinarily, floating sludge has all of the characteristics of a good sludge. It settles rapidly and produces a sparkling supernatant or subnatant liquor of low B.O.D. The floating tendency occurred in varying degrees, from a very thin layer over only part of the clarifiers to where the entire sludge blankets from two to four feet deep rose to the surface. During a period of mild floating the skimmers are an effective means of removing it from the tanks, but under severe conditions the skimmers proved to be of little value. Even by turning a fire hose on the surface of the tanks it was found impossible to keep the sludge down in the latter case.

Chemical tests and observation showed that in order to avoid either bulking or floating it was necessary to maintain from 2.0 to 3.0 p.p.m. of dissolved oxygen in the first half of the aerator and not more than 0.5 p.p.m. in the latter half. Furthermore, frequent determinations of dissolved oxygen at various parts of the aerator were essential, making it necessary to run analyses as late as midnight in order that the balance would not be upset on the following morning. At times the air produced by one blower is in excess of requirements, these requirements being as low as 0.3 cu. ft. per gallon. This condition only occurs during the summer months when the filters are operating at peak efficiency. It might be possible to divert part of the domestic primary effluent directly to the aerator during this period, the obvious advantage of this procedure being that the cost of pumping from the filter would be decreased.

In the winter months, increased hog kills and lowered filter efficiency may make it difficult to maintain the proper oxygen balance because of a limited air supply. It is estimated that 2.5 cu. ft. per gallon, which is in excess of blower capacity, may be required under the present system of operation. Whether or not this is the case will be determined during the coming winter.

This condition might also be relieved by the use of chemical treatment, as provided for in the plant design. To date except for short test periods, chemicals have not been added. From data obtained from these tests the addition of 25 p.p.m. of ferric chloride gave prac-

tically no improvement, while a removal of 49 per cent of B.O.D. is indicated when using 45 p.p.m. of ferric chloride, as against 40.4 per cent removal where flocculation without chemicals is employed. This will reduce the filter loading by an additional 1650 pounds of B.O.D. per day. However, it remains to be determined to what extent this additional reduction will affect the air requirements.

The present average dry weather flow is 2.00 m.g.d. of packinghouse waste and 2.50 m.g.d. of domestic sewage. The variation in strength and flow of the domestic sewage is not considered to be very great. The normal daily flow variation is from 1.4 to 3.8 m.g.d. while the B.O.D. ranges from 150 to 400 p.p.m. and suspended solids from 166 to 520 p.p.m. From these data it will be noted that the strength of domestic sewage is relatively high. The packinghouse waste variation is much greater, the flow varying from 0.63 to 4.3 m.g.d., whereas the B.O.D. ranges from 450 to 1800 p.p.m. and the suspended solids from 140 to 1200 p.p.m. These variations in flow have a considerable effect on the primary clarifier efficiencies. Furthermore 80 per cent of the packinghouse flow is received in 12 hours. The variation in packinghouse waste is further increased by difficulties that may be encountered at either the packinghouse or its pre-treatment plant. For instance, on two occasions an accident occurred to the brine line in the refrigeration plant resulting in a large quantity of ammonia being emptied into the sewer, causing on one occasion severe bulking of the activated sludge. Septic sludge is also frequently received from the packinghouse pre-treatment plant and observation has shown that any considerable amount of this septic material is definitely detrimental to the activated sludge plant.

The domestic sewage has an average primary detention period of 4.3 hours with maximum and minimum variation of from 7.6 to 2.8 hours, while the packinghouse waste has an average detention of 5.3 hours with a minimum of 2.5 and a maximum of 16.9 hours.

Because of the fact that the trickling filter effluent was pumped intermittently to the aeration unit, the flow variations were greatly accentuated by limitations in flexibility of the pumping facilities.

Experience proved that it was almost impossible to control the dissolved oxygen balance in the aerator unless some method could be found which would smooth out the wide fluctuation in flow. The only satisfactory method available was to allow the trickling filter effluent to back up in the gallery and to limit the pumping rate so that a constant rate of flow to the aerator could be obtained over relatively long periods. It was thought that this might result in a serious reduction in filter efficiency and it was with a great deal of concern that this procedure was adopted. However, no detrimental effect on the filters has been observed. On the other hand it is now comparatively easy to maintain a proper oxygen balance in the aerators. Furthermore, the wide fluctuation of flow in the final clarifiers has been decreased to the point where "false bulking" resulting from high overflow rates in excess of 1800 gallons per sq. ft. per day is no longer encountered.

The rate at which filter effluent is pumped to the aerator is 6.0 m.g.d. During the day period filter effluent backs up in the gallery. At night, after the gallery drains, the rate is reduced to 3 m.g.d. by switching pumps. Activated sludge is returned to the aerator at a maximum rate of 3 m.g.d., depending on the amount of sludge wasted. This gives detention periods in the aerator ranging from 4.0 to 6.0 hours, the average period being 4.8 hours. The corresponding final clarifier detention periods are 1.5 hours minimum and 3.0 hours maximum, with 2.25 hours as an average. The clarifier feed rates are 1800 gallons per sq. ft. maximum and 900 gallons per sq. ft. minimum, with corresponding overflow rates of 1200 and 600 gallons per sq. ft. per day respectively. Return and waste sludge are pumped at a high rate for two reasons:

1. In order to avoid denitrification with consequent floating of sludge when the oxygen balance in the aerator favors nitrification.
2. To prevent sludge from passing out over the wiers when the sludge is of a bulky nature.

This results in maintenance of a thin sludge blanket in the final tanks.

Experience indicates that better control may be maintained with a sludge slightly bulky in nature. Under these conditions a greater depth of clarifier might have been desirable for sludge storage, which would have permitted a higher concentration of sludge. The sludge varies from 0.5 to 1.6 per cent dry solids, depending upon its condition. From 2500 to 3000 p.p.m. dry solids in the mixed liquor is maintained. This varies from 1700 to 4500 p.p.m. with no apparent deleterious effect upon the plant effluent. The sludge index, i.e.

$$\frac{\%\text{ by volume of sludge after 30 minutes settling}}{\%\text{ suspended solids in mixed liquor}}$$

varies from 35 to 300. The 30-minute test has been of little value in control of plant operation. A rapid control test is made at least once a day, which consists in noting the sludge volume after 5 minutes of settling. The sludge must settle to 60 per cent by volume to avoid loss of sludge over the weirs. It appears that a sludge index computed on the 5 minute time basis is of more value in this particular case.

Results covering a 7 months period, from March to September 1937, inclusive, are given in Table I. During this period the packinghouse waste has been flocculated without chemicals prior to primary settling, the domestic sewage and packinghouse wastes are settled separately, and the combined primary effluents are dosed to only two acres of the trickling filters during the daytime period. During the period of low night flow only one acre of filter has been used. The purpose of this procedure is to increase the dosing rate on the filter. This gives a maximum dosing rate of 4.0 m.g.a.d. during the daytime and a minimum of 2.0 m.g.a.d. at night. Originally, with four acres of beds in service, the dosing rate varied from 0.5 to 2.0 m.g.a.d. This increase in dosing rate has been highly beneficial in reducing ponding

and minimizing filter fly nuisances. There was no apparent effect on B.O.D. reduction.

These results show a reduction in suspended solids in the primary clarifier of 54.4 per cent and a B.O.D. reduction of 40.8 per cent, for the packinghouse waste. Corresponding reductions in domestic sewage are 70.4 per cent and 54.3 per cent respectively. Although the B.O.D. and suspended solids are higher in the packinghouse waste, better removals were obtained in the domestic sewage because of two factors:

1. The ash content is higher in the domestic sewage.
2. The coarser solids in the packinghouse waste are removed in the packinghouse pre-treatment plant by fine screening and short period sedimentation.

The trickling filters during this seven-month period show an average removal of 4.3 per cent of suspended solids and a B.O.D. reduction of 42 per cent. These removals are low as a result of sloughing of the

TABLE I.—*Sioux Falls Sewage Treatment Plant Performance Record*

Results in Parts per Million

1937	Suspended Solids								5-day B.O.D.							
Month	PR	DR	Comb. Raw	DPE	PPE	Comb. PE	TFE	Final	PR	DR	Comb. Raw	DPE	PPE	Comb. PE	TFE	Final
March..	597	438	475	174	268	203	173	17.6	874	303	532	163	474	268	223	12.4
April....	674	428	529	114	352	224	154	7.5	845	297	405	113	575	245	160	9.6
May.....	578	438	522	174	333	261	585	11.9	582	344	550	148	432	345	276	12.6
June....	687	398	545	89	326	208	126	6.3	1040	330	668	168	660	356	138	11.7
July....	613	402	518	96	348	227	114	5.2	996	348	520	154	531	266	127	8.4
August..	944	332	492	95	231	126	99	10.8	1161	341	622	161	628	326	175	9.0
Sept.....	1146	386	644	97	391	205	148	9.2	1152	310	739	133	654	398	212	10.4
Ave.....	720	403	532	120	321	209	200	9.9	955	325	575	149	568	322	187	10.6

PR = Packinghouse Raw. DPE = Domestic Primary Eff. Comb. P.E. = Combined Primary Effluents.
DR = Domestic Raw. PPE = Packinghouse Primary Eff. TFE = Trickling Filter Eff.

filters, which unload every spring. Removals may appear to be lower than those obtained in the conventional trickling filter plant. However, it should be remembered that these filters are not followed by humus tanks, where a large portion of the solids would be removed. There are provisions, however, for conveying the trickling filter effluent direct to the final settling tanks, in case the aerator must be taken out of service. A special test conducted over a three-week period on a plant scale, using the final clarifiers as humus tanks, gave an average suspended solids removal of 55 per cent at a time when solids in the filter effluent averaged 265 p.p.m.

The average reduction of trickling filter effluent by the activated sludge plant is 95 per cent of the suspended solids and 94 per cent of the B.O.D. Thus the over-all removals for the entire plant for this period are as follows:

Suspended Solids ..... 98.6 per cent
B.O.D. ..... 98.9 per cent

A sparkling clear effluent was produced, averaging only about 10 p.p.m. each of B.O.D. and suspended solids. Dissolved oxygen in the plant effluent as it flows into the river is 85 per cent saturation. Tests for dissolved oxygen and B.O.D. on the Big Sioux River above and below the plant show practically no change. Based on counts at 37 degrees C. the reduction in total bacteria was 99.97 per cent.

The total solids removed in the plant amount to 20,040 pounds of dry solids per day, of which 12,560 pounds are removed by primary sedimentation and 7140 pounds in the secondary treatment. Solids to the extent of 340 pounds per day are lost in the filters, presumably by digestion. It is interesting to note that 59 per cent of all the solids removed are from the packinghouse waste. The packinghouse primary sludge contains 5.5 per cent dry solids, of which 78.6 per cent is volatile. The domestic clarifier receives all of the waste activated sludge. The combined domestic primary and waste activated sludges average 3.5 per cent dry solids, of which 74.3 per cent is volatile matter. The activated sludge alone contains 80.0 per cent volatile. From the above it is apparent that the amount of sludge pumped to the digesters each day amounts to 59,200 gallons of wet sludge containing 19,700 pounds of dry solids, of which 75.8 per cent is volatile matter. Former practice was to pump this sludge to the digesters which were operated in parallel. The total digester capacity is 459,000 cu. ft., so that the digester loading amounted to 1.29 pounds of dry solids per cu. ft. per month. This loading rate is low, but it may be ascribed to the high moisture content of the raw sludges, occasioned by the high volatile content, and the large percentage of activated sludge. It has been difficult to obtain segregation of solids in the digesters, therefore the digestion tanks have been operated on a straight displacement basis with no supernatant liquor being returned to the plant.

The actual detention or digestion period is approximately 58 days. The digested sludge, using single stage digestion, contained 7.0 per cent solids and 44.3 per cent volatile matter. It was black in color and comparatively free from odors. This sludge when applied to the drying beds at a depth of 18 inches was spadeable in two or three weeks during the summer months. By computation the reduction in total and volatile solids in the digesters amounted to 54.6 per cent and 74.7 per cent, respectively. Gas production has averaged 140,000 cu. ft. per day, or about 1.0 cu. ft. per capita for the connected equivalent population.

Recently two-stage digestion has been tried, using two of the three digesters as primary tanks and the other as a secondary. This has greatly increased gas production. Recent measurements show a total daily production of about 220,000 cu. ft. while the digested sludge volatile content dropped to 41.2 per cent. Indications, however, are that the present secondary storage period is inadequate to give appreciable thickening. At the present time gas is used for heating buildings, digesters, and incineration of the screenings, the excess being wasted.

Future plans will include utilization of the excess gas for power or otherwise.

Consideration of all the aspects of this problem indicate that under present conditions these wastes can be satisfactorily treated to a point where they no longer create a nuisance in the receiving body of water. The solids removed are also disposed of with available facilities. Whether or not the present high over-all removals can be maintained during the winter months must be determined in the light of further experience. At the present time plans are being made to re-circulate part of the filter effluent to the packinghouse primary clarifiers for the purpose of improving primary clarifier and trickling filter efficiencies.

Acknowledgment

The plant is under the general direction of Mr. Ellis O. Smith, Commissioner of Sewerage, whose whole-hearted cooperation has been an invaluable aid in meeting difficulties.

The cooperation of Supt. F. J. Connor and plant operators has been indispensable in maintaining proper balance and control of operation.

Acknowledgment is made of assistance given by Dr. A. J. Fischer of the Dorr Company.

THE EFFECTS OF INDUSTRIAL WASTES ON SEWAGE TREATMENT *

By Almon L. Fales

Metcalf and Eddy, Engineers, Boston, Massachusetts

The most common method of disposal of liquid wastes from industries, to avoid pollution of nearby streams or bodies of water, is by discharge into municipal sewerage systems where the sewers are available. Industrial wastes have generally been considered in the category of sewage and often little, if any, attention has been given by municipal officials to the possible effects of industrial wastes admitted to the sewers, and there have been serious consequences.

Much has been learned by unfortunate experience in regard to the effects of industrial wastes on sewerage works and sewage treatment processes, and considerable helpful information along this line has been published, but there is still great need of a better general understanding of the problems involved in the treatment of sewage containing industrial wastes. The object of this paper is to emphasize the importance of the relation of industrial wastes to the treatment of sewage.

Preliminary Considerations

Most municipal sewage contains more or less industrial wastes. In some cases the wastes present do not materially affect the sewage; in other cases, they cause a marked change in the quantity and/or character of the sewage, seriously affect processes of sewage treatment and greatly increase the cost of treatment.

The effects of industrial wastes discharged into sewerage systems upon the treatment of the sewage depend upon the character and relative quantity of the wastes present and the method of sewage treatment employed. There are many industrial processes producing liquid wastes and these wastes vary greatly in character and in volume. Some of these wastes do not require treatment, some require treatment quite different from that for domestic sewage, and others render sewage treatment processes inoperative.

The wastes from one kind of industry may differ greatly from those of another kind of industry, and there may be marked differences in the wastes from the same kind of industry at different places on account of different processes used. A single industrial plant usually produces several kinds of wastes, some of which may occasionally tend to counteract each other, but the combined wastes as discharged to the sewer usually vary materially in character and in rate of flow during a single day and on different days.

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The sewerage systems of large cities may receive considerable quantities of various industrial wastes without materially affecting the treatment of the sewage, while an equal quantity of the same wastes discharged into sewerage systems of relatively small cities or towns may have a great effect upon the sewage treatment. The relative quantity as well as the character of the industrial wastes discharged is, therefore, of fundamental importance.

The effects of industrial wastes on sewage treatment are influenced by the treatment plant features provided,—whether or not they include grit chambers, screens, oil-skimming tanks, sedimentation tanks, chemical precipitation equipment, intermittent filters, trickling filters, activated sludge plant, chlorination equipment, sludge digestion tanks, sludge drying beds, sludge dewatering equipment and incinerators for the dewatered sludge. Some sewage treatment plants may be able to handle the industrial wastes present without difficulty, while other types of plants may be unsuitable for an equal proportion of the same wastes. For some industrial wastes, no type of sewage treatment plant is suitable.

In 1933, information in regard to troubles due to industrial wastes at sewage treatment plants was obtained from a large number of city engineers and summarized.[1] Difficulties were reported by 93 cities or about 10 per cent of those reporting. In some cases, the trouble was caused by a combination of industrial wastes but the kinds chiefly responsible and the number of each were as follows: alcohol wastes, 2; apple acids, 1; cannery wastes, 6; creamery wastes, 9; dry cleaning, 3; garage and filling station wastes and miscellaneous oils, 24; hosiery and knitting mills, 2; laundry wastes, 19; malt wastes, 1; oil from factories, 4; oil refineries, 2; packing plants, 5; pickling plants, 2; produce plants, 1; rubber packing wastes, 1; steel mills, 1; tanneries, 1; wool wastes, 2. These do not include all of the industrial wastes which have affected sewage treatment.

General Types of Industrial Wastes Which Affect Sewerage Works or Sewage Treatment Processes

The general types of industrial wastes which have affected sewerage works or sewage treatment processes include the following:

1. Practically clean waters from cooling, condensing or other processes, which do not require any treatment and needlessly increase the quantity of sewage to be treated, thereby reducing the efficiency of treatment or increasing the size of sewerage works required.
2. Excessively hot liquids causing injury to sewers, releasing offensive vapors or gases and promoting septic action and consequent objectionable odors at the sewage treatment plant.
3. Wastes containing inflammable substances, such as gasoline, which may cause explosions in sewers, pumping stations or sewage treatment plants resulting in damage to property, in injury to persons and sometimes in loss of life.

4. Strongly acid wastes causing disintegration of concrete sewers and plant structures and interfering with biological processes at sewage treatment works.
5. Wastes containing other chemicals which interfere with sewage treatment processes, including those having a high chlorine demand affecting chlorination of the sewage and those having a disinfecting action, affecting biological processes of sewage treatment.
6. Wastes carrying grease or oil, causing objectionable conditions at sewage treatment plants and in some cases a fire hazard and interfering with biological processes unless the grease is effectively removed by skimming from preliminary tanks.
7. Other wastes injuriously affecting the appearance or odor of sewage and plant effluent.
8. Wastes excessively high in suspended solids, reducing the efficiency of sewage treatment and increasing the quantity of sludge produced and affecting its quality in connection with digestion and/or dewatering.
9. Wastes containing suspended solids of high specific gravity which form deposits in sewers, reducing the capacity and causing sewer clogging, overload grit chambers, if available, and accumulate in sedimentation and sludge digestion tanks, reducing the working capacity and requiring special means for removal.
10. Wastes containing coarse suspended matter, tending to block sewers, overload screens and form troublesome scum in sedimentation and sludge digestion tanks.
11. Wastes excessively high in dissolved and colloidal organic matter, overloading sewage treatment plants, reducing efficiency of treatment and creating offensive odors due to putrefaction.
12. Wastes subject to precipitation of solids, causing clogging of filters and increasing the quantity of sludge produced and interfering with sludge digestion and/or dewatering of the sludge.

Clean Waters

Cooling or condensing waters, which generally are relatively large in volume, should be separated from the objectionable wastes to be treated or discharged into sewerage systems, although dilution of very strong wastes is advantageous for some methods of industrial wastes treatment. Other unobjectionable wastes requiring no treatment should also be separated as far as practicable for discharge directly to the stream.

The importance of separating the practically clean waters from the objectionable wastes is well illustrated by the experience at Paterson, New Jersey, where there are many silk-dyeing establishments. The Passaic Valley trunk sewer became overloaded in places at times of peak flow, resulting in overflows and consequent pollution of the Passaic River. During the years 1930 and 1931, unobjectionable wastes

amounting to an average of 10.9 million gallons per day and a rate of 12.2 million gallons per day during working hours, based on normal business conditions, were diverted from the sewer, eliminating the sewer overflows to the river and resulting in an estimated annual saving of $35,000 for sewage disposal. The value of the trunk sewer capacity corresponding to the peak flows diverted, based on the cost to Paterson for its allotted capacity, amounted to about $908,000. The relatively large volumes of unobjectionable tin weighting waste had already been diverted to the river in nearly all cases.

Hot Liquids

Hot liquids having a temperature above 140° F. should be cooled before admission to sewers. This may be accomplished by mixing with cool wastes to be treated, if available in sufficient quantity, or by ordinary cooling ponds with spray nozzles if cooling by storage alone is impracticable. The use of heat exchangers and utilization of the heated water may be advantageous.

At the textile mills of the Lewis Manufacturing Company in Walpole, Massachusetts, the kier wastes having a temperature as high as 212° F. are cooled to 120° F. prior to discharge into the Walpole trunk sewer connecting with the Neponset Valley sewer of the Boston South Metropolitan District. A heat exchanger is used with counterflow of cooling water, thus furnishing hot water for use in the mills.

Inflammable Wastes

Inflammable substances like gasoline must be kept out of sewerage systems. If sewer connections are permitted for wastes containing gasoline, effective traps should be maintained on the drains from garages, filling stations and other establishments where gasoline is used or stored.

Explosions in sewers have occurred in various places, blowing manhole covers into the air, damaging property, injuring persons and sometimes causing loss of life. Explosions due to the presence of inflammable wastes in the sewage have also occurred at sewage pumping stations and at sewage treatment plants.

A celebrated case is that at Newburgh, New York,[2] in 1929, where a series of sewer explosions in the business district caused the death of one person and serious injury of a score of others, and property damage estimated at $200,000 to $300,000. Although conclusions differed as to whether the explosions were caused by illuminating gas leaks into the sewer or by gasoline discharged into the sewer, either could have caused the explosions.

A notable example of an explosion in a sewage pumping station occurred in 1914 at the East Boston sewage pumping station of the Metropolitan District Commission, caused by gasoline in the sewage. The explosion resulted in the death of six men and serious injury of at least three others, and necessitated the rebuilding of the station.[3]

This explosion was described [4] and the results of an investigation of explosive mixtures were published.[5]

Another example of a sewer explosion is that at Los Angeles in 1929 in which case according to Knowlton,[6] 30 manhole covers weighing 220 pounds each were blown into the air, some going as high as 25 feet, according to eye witnesses, and on falling struck the pavement with such force that they were broken to pieces. It was considered miraculous that no one was injured and no automobiles were damaged, as the explosion occurred during heavy traffic. The explosion was attributed to the ignition of gasoline vapor in the sewer manholes by a city asphalt heater working along the sewer line.

A more recent example of a sewer explosion is that at Springfield, Massachusetts, in December 1934, where a severe explosion occurred in a large sewer, causing great damage to the sewer itself. This explosion was attributed to the escape of gasoline into the sewer from nearby gasoline pressure pipes or storage tanks.

Middletown, New York,[7] a few years ago experienced a fire at its sewage treatment plant, which was attributed to the ignition of gasoline floating on the sewage coming down the sewer. The flames followed the sewage into the building but the fire was extinguished before causing serious damage.

Acid Wastes

Acid wastes, including those from metal pickling and chemical works, have caused disintegration of concrete sewers at various places. At Worcester, Massachusetts,[8] in 1897 it was found that the invert of a large sewer had been attacked by acid pickling liquor in spite of the fact that the sewer carried the entire flow of the sewage of the city then having a population of 100,000 and the natural flow of a small stream amounting to about 3 million gallons per day in dry weather.

At Pawtucket, Rhode Island, several years ago it was found that a new concrete sewer was being seriously affected by pickling liquor from a wire mill. The company was ordered to keep these wastes out of the sewer. Studies indicated that it would be practicable to treat the wastes for the recovery of sulfate of iron.

At Milwaukee, according to Heisig and Brower,[9] several sewers in the vicinity of plants discharging acid wastes, showed evidence of disintegration and in one or two instances, sewer structures were completely destroyed. The industries producing these wastes are now required to keep them out of the sewers or to neutralize the acid prior to discharge into the sewers.

At Fostoria, Ohio, according to Cameron,[10] pickling liquor in the sewage caused corrosion of pumps and disintegration of concrete at the sewage treatment plant. This acid waste was excluded from the sewage.

Neutralizing the acidity of such acid-iron wastes with lime, involves large expense and causes the precipitation of hydroxide of iron which may have objectionable effects as will be discussed further on.

The Maryland State Board of Health [11] after studies on the effect of acid wastes, concluded that a pH of 4.0 is the minimum permissible for industrial wastes to be discharged into concrete sewers. This standard has been adopted by the city of Baltimore.

Bacterial decomposition of sewage containing sulfates and consequent production of hydrogen sulfide, has caused the disintegration of concrete sewers in various places. The presence of industrial wastes has sometimes been responsible for such action. Gordon [12] described an experience in Washington, D. C., where the disintegration of a sewer was caused by the admixture of yeast wastes with the sewage, increasing the sulfate content and raising the temperature of the sewage, thus promoting bacterial decomposition. The remedy decided upon was the application of chlorine to the sewage above the point of discharge of the yeast wastes to prevent bacterial decomposition and consequent production of hydrogen sulfide.

Other Wastes Containing Harmful Chemicals

Reference has been made to the effect of acid wastes on biological treatment processes, when present in sufficient amount to render the sewage acid. Strongly alkaline wastes also have a disinfecting action; for example, the kier wastes at cotton textile mills, the digester wastes at certain paper mills and the wastes from the Steffens process at beet sugar factories.

At Greenwich, Connecticut, the spent developer at a publications establishment had a high chlorine demand, interfering with the chlorination of the sewage. It was recommended that this liquor, which was small in volume, be discharged to waste land together with the acid waste from electro-plating.

Cyanide waste from metal plating, when present in sufficient amount, also has a toxic effect on bacteria. Oeming [13] cites an experience at Muskegon Heights, Michigan, where trouble with sludge digestion was attributed to the accumulation of copper oxide precipitated from copper cyanide.

At New Haven, Connecticut,[14] it was found that the wastes from copper working industries present in the sewage precluded the use of the activated sludge process for the treatment of the sewage.

At the old Calumet sewage treatment plant of the Sanitary District of Chicago, according to Dr. F. W. Mohlman, Chief Chemist, paint industry wastes containing copper, arsenic and lead compounds, until controlled, interfered seriously with the operation of the activated sludge plant and an experimental trickling filter.

Waste Grease and Oils

Oil, grease and tarry substances have caused objectionable conditions at many sewage treatment plants and have interfered with the efficiency of biological processes, particularly where effective means for preliminary removal of this material were not available. The oil

and tarry wastes come principally from automobile service stations, garages, filling stations, oil refineries and gas works, and the grease comes principally from meat packinghouses, tanneries and wool scouring plants. At Hudson, Massachusetts [15] grease from wool scouring wastes discharged into the sewers caused clogging of sand filters to such an extent that the company was compelled to take these wastes out of the sewers. Subsequently, the wool scouring wastes were treated by the acid cracking process for recovery of grease.

At Worcester, Massachusetts, Lanphear [16] found oil and grease very troublesome. This material, which came largely from a slaughter house and tannery, caused the surface of the Imhoff tanks to be objectionable in appearance and in odor. Most of this material collected in the last two sedimentation compartments of the last tank in each battery, from which it was being removed twice a month to small sand beds, and the accumulation burned about twice a year. The burning caused a smoke nuisance but only for a few hours each time. With this method of grease removal, the efficiency of the trickling filters apparently was not affected.

At Milwaukee,[9] where only grit chambers and fine screens are available ahead of the activated sludge plant, oil, grease and tarry wastes were found to be a nuisance and a source of great expense and caused a marked reduction in the purification efficiency. Consequently, pretreatment by suitable skimming tanks or grease traps has been required and where there is danger of much oil being discharged, no sewer connection is permitted. In order to avoid the possibility of discharge of oil from automobile drain pits, the Public Works Department of the city calls, on request, to collect the waste oil which is then stored and used for fuel in the burning of garbage at the garbage incineration plant.

Oily, fatty and greasy wastes from packinghouses and allied industries not only caused a nuisance at the sewage treatment plant but frequently resulted in the stoppage of the sewers into which they were discharged. When the attention of the manufacturers was called to the loss of this material, they were glad to provide adequate grease removal equipment.

Grease, oil and tarry substances should be effectively removed from wastes before discharge into municipal sewers. Suitable skimming tanks or grease traps must be installed on the drains and maintained in good working order by removal of the accumulations as often as necessary. Such traps should be inspected periodically by the municipal authorities and where negligence is found, permission to discharge the wastes into the sewers should be denied. Collection of waste oil by the municipal authorities as at Milwaukee and elsewhere, may be a wise precaution. In some cases where skimming tanks or grease traps cannot safely be relied upon, no sewer connection should be permitted for the wastes, thus requiring that they be taken care of on the premises.

Other Wastes Affecting Appearance or Odor of Sewage and Treatment Plant Effluent

Other industrial wastes, if present in sewage in sufficient proportion, may affect the appearance or odor of the sewage and plant effluent. The sewage may become colored and the odors of the wastes may persist in the sewage or become worse. The treatment plant effluent may also be affected to some extent.

At Worcester, Massachusetts, according to Lanphear,[16] dye wastes have colored the sewage and Imhoff tank effluent at times, but the color has been removed by the trickling filters. He also found that lime wastes from a tannery were a source of disagreeable odor at times, particularly from the trickling filters.

At Greenwich, Connecticut, wash water after developing plates at a publications establishment caused the sewage, plant effluent and stream to be highly colored at times. The solution of this problem was found in the storage of these wastes for uniform discharge during the 24 hours.

At Gastonia, North Carolina according to Henderlite,[17] highly colored wastes from textile dye plants discharged in batches, have caused the sewage, activated sludge effluent and stream to be highly colored. These wastes also disrupted the activated sludge process and caused serious trouble from sludge bulking. The trouble was largely overcome, although at considerable expense, by the application of ferric chloride solution which precipitated the color, increased the efficiency of treatment and eliminated the sludge bulking.

Various industrial wastes such as cannery wastes, creamery wastes, distillery wastes, tannery wastes and other wastes high in putrescible organic matter, have caused odors at sewage treatment plants due either to the odor of the wastes as discharged or to the odors from decomposition, particularly hydrogen sulfide.

Unless adequate provisions can be made at the sewage treatment plant to prevent these objectionable effects, the wastes should be treated at the industrial plant.

Wastes High in Suspended Solids

Many industrial wastes are much higher in suspended solids than is domestic sewage. Such wastes discharged into sewerage systems have, in numerous instances, greatly increased the suspended solids in the sewage affecting the efficiency of sewage treatment and the quantity and quality of sludge to be handled.

At Akron, Ohio, for example, the wastes from the rubber-reclaiming plants were found to contain more suspended solids than the sewage from the entire city. The Imhoff tank-trickling filter plant was designed on the basis of the removal by the manufacturing plants of a large percentage of these solids before discharging the wastes into the city sewage. This was not accomplished prior to putting the sewage treatment works in operation, thus causing a tremendous overload

on the Imhoff tanks and necessitating the lagooning of sludge and interfering with the operation of the trickling filters.

Oeming [13] refers to the effects of paper mill machine wastes, or white water, on a sewage treatment plant at Monroe, Michigan, where considerable difficulty was experienced with excessive volumes of sludge. He points out that the solution of such paper mill wastes problems is to be found in the re-use of the white water and recovery of the fibre.

In some cases, solid wastes, such as wet grains and spent hops from the brewery industry, paunch manure at slaughter houses, and press cake in the manufacture of soap, yeast, beet sugar and other products have been flushed to the sewer as the most economical method of disposal, thus greatly increasing the suspended solids in the sewage. At Milwaukee,[9] and elsewhere, it is required that such solid wastes be kept out of the sewers.

The suspended solids in different industrial wastes vary greatly in character, some being largely organic matter and some mostly mineral matter. Some are very heavy and some very coarse and fibrous. Some wastes like tannery wastes contain both heavy and coarse solids. The effects on sewage treatment depend on the character as well as the amount of suspended solids. Examples of the effects of wastes containing different kinds of suspended solids will be considered.

Wastes Containing Solids of High Specific Gravity

Wastes containing solids of high specific gravity, such as sand, dirt, lime impurities and carbon, have caused solid deposits in sewers and at sewage treatment plants in a number of cases.

At Milwaukee,[9] discharges from stone and marble-working plants and acetylene gas manufacturing plants, and beam house wastes from tanneries have caused deposits in sewers, necessitating pre-sedimentation. The combination of lime, hair and fleshings in the beam house wastes formed a sort of mortar tending to promote the clogging of the sewers, so that preliminary screening as well as sedimentation was required.

In the Massachusetts South Essex Sewerage District, where a number of tanneries are located, trouble has been experienced not only with deposits of hair and lime in the sewer, but a hard coating of carbonate of lime was formed, seriously limiting the sewer capacity. The solution of this problem proposed by Mr. H. W. Clark,[18] former Chief Chemist of the Massachusetts State Department of Health, is the treatment of the wastes with carbon dioxide as by passing flue gases through them.

Oeming [13] points out that the flume water from beet sugar factories contains about 40 times as much grit as ordinary sewage does, so that this material would be likely to overtax the usual grit handling facilities at sewage treatment plants.

At Worcester,[16] foundry sand passing through the grit chambers has been found in the side channels of the Imhoff tanks, and it is not

known to what extent it may have accumulated in the Imhoff tanks. At Fitchburg, Massachusetts,[19] heavy solids accumulated in the Imhoff tanks to such an extent that these tanks had to be cleaned out, a sand ejector being used for this purpose, operated with city water from a fire hydrant.

At Fostoria, Ohio,[10] the digestion chamber of the Imhoff tanks failed to function because of the accumulation of dense solids in carbon-grinding wastes, necessitating the cleaning out of the Imhoff tanks. Presedimentation of these wastes was required.

Wastes Containing Coarse Suspended Matter

Wastes containing coarse or fibrous suspended matter such as packinghouse wastes, tannery wastes, wastes from woolen mills and brewery mash have clogged sewers and caused excessive amounts of scum in sedimentation and sludge digestion tanks.

Reference has already been made to Milwaukee experience with tannery wastes clogging sewers due to the combined effect of lime and coarse suspended matter.

At Kitchener, Ontario, according to Dr. George G. Nasmith, the presence of fibrous material in the wastes from wool and felt mills and tanneries caused a heavy matted scum to form on the separate sludge digestion tanks and this had to be removed by hand.

Warrick [20-21] also cited difficulties in sewage treatment due to woolen mill wastes containing a large amount of short wool fibres which adhered to the sewage solids, exerting a bonding effect, thus tending to form a tough scum in Imhoff and separate sludge digestion tanks.

The spent grain mash from breweries is generally recovered for cattle feed. During the days of prohibition, home brew mash was sometimes discharged to the sewer instead of into the garbage can where its presence might be noticeable and lead to trouble. The presence of the home brew mash caused troublesome scum at sewage treatment plants. For example, at the sewage treatment plant of the Lawton Mills Corporation at Plainfield, Connecticut, this mash set up acid digestion in the Imhoff tank and caused the sludge to rise into the scum compartments from which it had to be drawn off to the sludge beds until favorable digestion was established in the scum by the addition of lime, after which the bulk of the scum solids settled into the sludge compartment and the Imhoff tank again worked normally.

Wastes High in Dissolved and Colloidal Organic Matter

Wastes excessively high in dissolved and colloidal organic matter, such as those from distilleries, creameries, canneries, packinghouses, tanneries and paper mills, have overloaded sewage treatment plants, reducing the efficiency of treatment and in some cases causing offensive odors and necessitating odor control.

The beer slop from distilleries is many times as strong as sewage, so that only a small proportion of this waste can be admitted to sewage

treatment works without creating a great increase in load. At Peoria, Illinois, Kraus [22] found that when beer slop from the manufacture of butyl alcohol and acetone was treated with the sewage, by preliminary sedimentation and the activated sludge process, the odors created were so objectionable that preliminary digestion of the beer slop was resorted to, although this beer slop was considerably less concentrated than ordinary distillery slop.

At Stockport [23] in England, the de-alcoholized wort from the manufacture of alcohol from crude molasses by acid fermentation caused such an overload at the sewage bio-aeration treatment plant, in spite of equalizing the flow and attempted pre-treatment, that the industry was obliged to abandon its plant which was relocated on the seacoast.

Warrick [20-21] cites the overloading of a sewage treatment plant of a small city in Wisconsin by creamery wastes including some buttermilk and whey, and pea-cannery wastes, which caused foaming in the Imhoff tank, destroying the efficiency of sedimentation. The bulk of the solids in the tank accumulated as scum in the gas vents. Pre-treatment of creamery wastes, excluding buttermilk and whey, by a trickling filter, and pre-treatment of the pea-cannery wastes by screening and chemical precipitation, were effective in overcoming operating difficulties at sewage treatment works receiving these wastes.

Cox [24] cites the overloading of the sewage treatment plants at Holley and Freedonia, New York by cannery wastes.

Packinghouse wastes have frequently overloaded sewage treatment plants. Even after pre-treatment to remove the bulk of the solids and grease, these wastes are much stronger than sewage. At Chicago,[25] it was estimated that the wastes from packinghouses in 1920 were equivalent in B.O.D. (biochemical oxygen demand) to the sewage from 1 million people.

At Sioux Falls, South Dakota,[26] the trickling filter sewage treatment plant became overloaded, due to packinghouse wastes, so that provision was made for ferric chloride treatment of the packinghouse wastes, and an activated sludge unit was added for the treatment of the trickling filter effluent. The treatment plant is so designed that the packinghouse wastes and domestic sewage can be treated independently. (See this issue, page 959.)

At Cedar Rapids, Iowa,[27] packinghouse wastes after grease removal and screening through 40-mesh screens at the factory, are pumped to an equalizing tank at the sewage treatment plant and treated by an aerated grease removal unit and at times by chemical precipitation with ferric chloride after controlling the alkalinity with sulphuric acid, and the chemical effluent is pumped to the trickling filter dosing tanks of the main sewage treatment plant. Provision is made for odor control by chlorination. The sludge from the treatment of the packinghouse wastes is digested with the sewage sludge.

Tannery wastes are also much stronger than domestic sewage even after pre-treatment to remove the coarsest and heaviest solids. At Gloversville, New York, the sewage contained such a large proportion

of tannery wastes that a sewage experimental station was operated there some years ago before designing the sewage treatment works. This sewage was found to be much stronger than ordinary domestic sewage and the treatment plant was designed accordingly. The tanneries were required to build and operate tanks for the removal of the excessive quantities of solids.

In some cases, a combination of industrial wastes from different sources has been responsible for overloading sewage treatment plants. At Orrville, Ohio, as described by C. C. Hommon,[28] wastes from three milk-processing plants, a slaughter house and a food-processing plant making apple butter and preserves, rendered ineffective the sewage treatment plant, consisting of a septic tank, contact beds and sand filters, and necessitated the construction of a new sewage treatment plant comprising sedimentation tanks with mechanical sludge removal equipment, separate sludge digestion tank and reconstructed sand filter beds. Ferric chloride is used as a coagulant to assist sedimentation during the busy seasons at the industries.

Wastes Subject to Precipitation of Solids

At Worcester, Massachusetts, the presence of large amounts of pickling liquor, or acid-iron wastes, from the wire mills and foudries, was an important factor in the selection of chemical precipitation as the method of sewage treatment by the original plant built prior to 1890. Milk-of-lime was added to the sewage in sufficient amounts to neutralize the acid and precipitate the iron, as indicated by a pink color on adding a few drops of phenolphthalein to the treated sewage. This treatment removed a large percentage of the suspended and colloidal matter in the sewage and produced a practically clear effluent, but the treatment was held to be inadequate.

Intermittent sand filters were added and the strongest of the sewage, not including doses of acid-iron wastes, was selected for filtration up to the capacity of the filter beds available. The acid-iron wastes in the sewage had an inhibiting effect on bacterial action in the filter beds, but a good effluent was produced, except that it contained more or less precipitated iron hydroxide. Dissolved iron in the sewage on oxidation in the filter beds was precipitated in the joints of the underdrains and in the gravel around the joints, causing clogging and necessitating periodic re-laying of the drains. Doses of acid-iron wastes coming in contact with tannic acid from doses of tannery wastes, formed tannate of iron, a bluish black ink, and this color could be removed by chemical precipitation only at great expense.

On account of the high cost of chemical precipitation and sludge disposal, the chemical precipitation plant was abandoned in 1925 and an Imhoff tank-trickling filter plant constructed, some of the sand filter beds being utilized as sludge beds. Dissolved iron in the sewage is precipitated in the trickling filters but not in sufficient amount to cause filter clogging, the precipitated iron being carried away by the filter

effluent and largely removed by the secondary sedimentation tanks, thus greatly increasing the quantity of sludge produced in these tanks.

Lanphear [16] describes the effect of the interaction of the acid-iron wastes and lime wastes from a large tannery prior to the business depression, causing the precipitation of iron in the sewers or in the Imhoff tanks and a consequent large increase in the quantity of sludge, causing an abnormal load on the sludge digestion compartments and necessitating frequent removal of sludge from the Imhoff tanks to maintain efficient clarification of the sewage.

At Fostoria, Ohio, as described by Cameron,[10] the precipitation of hydroxide of iron from acid-iron wastes in the sewage, by oxidation, completely clogged the trickling filter, necessitating the washing of the filter stone.

At Cleveland, Ohio,[29] several years ago, acid-iron wastes in the sewage at the southerly sewage treatment works were responsible for the precipitation of hydroxide of iron in the trickling filters to such an extent that the filters were shut down from September, 1929, to March, 1930, until these wastes were diverted from the sewers.

Acid-iron wastes were detrimental to the activated sludge treatment of sewage at Elyria, Ohio,[30] where they caused clogging of air diffuser plates, and at Indianapolis, Indiana,[31] where they had a germicidal effect on biological life.

Policy with Reference to Admission of Industrial Wastes to Municipal Sewers

The experience in the treatment of sewage containing industrial wastes demonstrates (1) that some wastes should be excluded from the sewers, (2) that some wastes should be admitted only after storage for equalizing the flow and/or quality of the wastes, and (3) that some wastes should be admitted only after suitable pre-treatment.

It is unreasonable for a municipality to exclude all industrial wastes from the sewers. It is generally a wise policy to admit to the sewerage system organic wastes requiring treatment, after such preliminary treatment as may be needed to prevent an undue burden for sewage treatment, and to exclude wastes which might injuriously affect the sewers, pumping stations or treatment plant structures or interfere with sewage treatment processes. New sewage treatment plants should be designed with reference to the industrial wastes to be treated.

In general, the following wastes should be excluded from the sewerage system:

1. Large volumes of practically clean water,
2. Excessively hot liquids,
3. Inflammable wastes,
4. Strongly acid wastes,
5. Wastes containing harmful chemicals,
6. Wastes which would not be improved by the sewage treatment provided, and

7. Wastes which cannot be satisfactorily treated by processes of sewage treatment.

Pre-treatment should generally be required in the case of the following wastes:

1. Wastes which are somewhat acid in nature,
2. Wastes containing grease or oil,
3. Highly colored wastes or wastes creating offensive odors,
4. Wastes excessively high in suspended solids or subject to the precipitation of excessive amounts of solids,
5. Wastes containing coarse or heavy solids, and
6. Wastes excessively high in dissolved and colloidal matter.

Some municipalities, like Milwaukee [9] which is a highly industrialized city, have the power by law to regulate the quantity and kind of industrial wastes discharged into the sewerage system. The Milwaukee Sewerage Commission is empowered to order the removal of wastes from the sewers or pre-treatment of the wastes prior to discharge into the sewers, and to issue permits for all industrial connections to the sewers. The requirements are based on thorough industrial wastes surveys to determine the quantity and character of all the industrial wastes. Through helpful co-operation, the Commission seeks to maintain the good will of industry as this is considered essential in the solution of problems arising from the discharge of industrial wastes into the sewerage system.

Many municipalities do not have the authority to control the discharge of industrial wastes into the public sewers, and co-operation of the industries in removing wastes from the sewers or in providing preliminary treatment before discharge has not always been easy to obtain. Even the regulation of the flow of wastes by building and maintaining storage tanks has been impossible to secure in some cases. The passage of suitable ordinances has sometimes been required to secure the desired results.

In view of the need of controlling the admission of industrial wastes to sewerage systems, it is important that suitable laws or ordinances be in force. Examples of laws and ordinances for the protection of sewers and sewage treatment works were cited by Coburn.[32] Such laws and ordinances should provide for periodic examination of industrial wastes discharged at the different industries and supervision of operation of any pre-treatment works required, not including recovery processes which the industries may find it advantageous to adopt. Municipalities should co-operate with industries to the fullest extent practicable. However, access to the sewers should be denied the existing or new industries which fail to comply with the requirements. This policy is in harmony with the recommendations in the 1930 report of the Joint Advisory Committee on River Pollution in Great Britain.[33]

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Discussion of the Paper "The Effects of Industrial Wastes on Sewage Treatment" (Almon L. Fales)

By A. D. Weston

Chief Engineer, Massachusetts Department of Public Health, Boston, Mass.

The subject which has been so excellently covered by Mr. Fales is one which has not always been given careful consideration by engineers, in the design of sewerage systems and sewage treatment works, and by local authorities when inviting industries to establish in their communities. Mr. Fales has so thoroughly covered the subject that the writer will limit his remarks to certain Massachusetts practices, the laws relating thereto, and certain experimental work conducted by the Department of Public Health at its Lawrence Experiment Station.

Massachusetts problems, relating to the disposal of industrial wastes in sewerage systems, have been concerned with surcharging of, and injury to, the systems, reduction in their capacity due to deposits and incrustations, and overcrowding of, and injury to, sewage treatment works.

Very striking examples of the effect of surcharging sewers by industrial wastes were disclosed in a recent investigation by a Special Commission, established under the provisions of Chapter 42 of the Massachusetts Resolves of 1935, to investigate the discharge of sewage into Boston Harbor and its tributaries. This investigation showed that certain parts of the North Metropolitan Sewerage System in Metropolitan Boston were grossly inadequate to receive the large amounts of industrial wastes discharged into them and in one section, where a maximum of over 5 m.g.d. of industrial wastes were being discharged into a trunk sewer, the designed capacity of which was only about 3.7 m.g.d., manholes were raised and manhole covers were sealed down to increase the hydraulic gradient without the sewage overflowing. Similar conditions have been encountered in the densely developed industrial sections of the South Essex Sewerage District.

Many of the sewers in the easterly part of the State, especially in the city of Boston, were constructed to divert surface drainage (in Boston, until 1833, fecal matters were rigidly excluded from the sewers and were only admitted in that year because of the prevalence of cholera in the previous year), and their use as combined systems probably

would overtax their capacity even without the introduction of large quantities of industrial wastes.

Massachusetts laws are sufficient, if properly exercised, to prevent these abuses. For example, Section 10 of Chapter 83 of the Tercentenary Edition of our General Laws authorizes the aldermen of a city or the sewer commissioners, selectmen or road commissioners of a town, to make regulations to prevent the entrance or discharge into sewers of any substance which may tend to interfere with the flow of sewage or the proper operation of the sewerage system or disposal works and for the construction and use of particular sewers. Under this chapter, the Supreme Judicial Court and the Superior Court are given jurisdiction in equity to restrain the unlawful use of sewers. In connection with the so-called Boston Metropolitan Sewerage District, the Commission operating that system, under Chapter 92 of our General Laws, has the power to direct, control and regulate connections between local sewers and the sewerage system of the district. In this chapter, surface or storm waters, and such other waters as specified by the Department of Public Health are designated as "waters" and all other waters and sewage are designated as "sewage."

Under Section 127 of Chapter 111 of our General Laws, the Board of Health of a city or town may make and enforce regulations for the public health and safety relative to connections with sewers, and violations of such regulations are punishable by a fine of not more than $100. Under all modern Massachusetts legislative acts which enable municipalities to establish sewerage systems, provisions are made for the adoption of rules and regulations.

Probably the most troublesome conditions encountered in any sewerage system in Massachusetts are those which have resulted from the discharge of industrial wastes into the sewerage system of the South Essex Sewerage District. Chapter 312 of the Acts of 1904, which authorized the construction of a system of sewers in Peabody and Salem (now a part of the South Essex Sewerage District) provides in Section 1 that "the nature or quality of the sewage to be discharged into or through the trunk sewer" in Salem and Peabody "shall be subject to regulation by the State Board of Health." In accordance with the provisions of that section, the then State Board of Health did adopt rules and regulations which provided that the industrial wastes should first be treated by means of settling tanks, screens, strainers, precipitants, filters or by such other means as should from time to time be found necessary to remove all solids in suspension that would not be carried along by the minimum current in any part of the trunk sewer or which might either alone or in combination with other matters tend to cause sedimentation or deposition in the sewer or tend to obstruct or impede the flow therein or be injurious to pumps or sewers or be likely to create a nuisance within or without the said sewers. Such regulations were necessary as the sewers had become badly clogged by deposits of sludge causing the sewage to back up to the exclusion of considerable quantities of foul wastes which overflowed

into neighboring water courses. Cleaning the public sewers in these municipalities to remove the sludge and other matter entering them also was costly. The writer has spent considerable time experimenting with the sedimentation of some of the tannery wastes entering these sewers, and the results of these experiments showed conclusively that in many instances objectionable deposits in the sewers could not be prevented, except by the expenditure of considerable sums of money by the industries for the construction of adequate treatment works, because the supernatant liquor resulting from long periods of sedimentation of certain of the industrial wastes, when mixed with the supernatant liquor from sedimentation of other wastes, caused much flocculent matter to settle out on the sides and bottom of the sewers. The work of H. W. Clark, Chief Chemist of the Department of Public Health, retired, in the treatment of caustic lime wastes from tanneries in this district by the use of flue gas is of interest. Because of the abuse of this sewerage system, it was necessary in the years 1926 to 1928 to supplement some 11,500 feet of outfall sewer of this district which had been so incrustated with caustic lime as to reduce its capacity below that at which it was practicable to operate. Since 1925, the authority to regulate the character of sewage, drainage or other wastes discharged into these sewers has rested with the South Essex Sewerage Board and the following regulations have recently been adopted by that Board:

1. No corporation, firm nor person shall discharge or cause or allow to be discharged into any sewer under the control of the South Essex Sewerage Board, or any sewer tributary thereto within the South Essex Sewerage District, any sewage, drainage, substances or wastes containing caustic lime in excess of seventy-five parts per million by weight.

2. No corporation, firm nor person shall discharge or cause or allow to be discharged into any sewer under the control of the South Essex Sewerage Board, or any sewer tributary thereto within the South Essex Sewerage District, any sewage, drainage, substances or wastes containing greasy or fatty matters in excess of three hundred parts per million by weight.

3. No corporation, firm nor person shall discharge or cause or allow to be discharged into any sewer under the control of the South Essex Sewerage Board, or any sewer tributary thereto within the South Essex Sewerage District, any sewage, drainage, substances or wastes containing suspended solids in excess of five hundred parts per million by weight.

In connection with the discharge of industrial wastes into sewerage systems in a manner which may have an unfavorable effect on the proper operation of sewage treatment works, Chapter 83, Section 7, of our General Laws, provides that, if the Department of Public Health determines upon examination that a filter bed or other works for the treatment, purification and disposal of sewage causes the pollution of a stream, pond or other water, or is likely to become a source of nuisance or create objectionable conditions in its neighborhood *because of the discharge into the system of manufacturing waste or other substance of such character as to interfere with the efficient operation of the treatment works,* the Massachusetts Department of Public Health may, if

necessary, prohibit the entrance of such waste or other material, or may regulate the entrance thereof into the system, or may require the treatment of such wastes or other material in such manner as may be necessary to prevent its interference with the operation of the works. In the exercise of its authority granted under this act, the Department of Public Health has assisted cities and towns and others relative to the treatment of industrial wastes.

In order to advise in these matters, the Engineering Division of the Department has found it necessary to carry out experiments on certain wastes at the Lawrence Experiment Station under the direction of George O. Adams, Chief Chemist, where facilities are provided to experiment under conditions similar to those which it is expected would be encountered in actual sewage disposal practice. The results of these experiments with the exception of those on yeast wastes in 1909 will be found in detail in the reports of the Department for the years 1931 to 1937, inclusive.

Distillery Wastes.—The work at the Lawrence Experiment Station in connection with distillery wastes was in relation to wastes from the distillation of various grains, particularly rye and corn, in the production of rye and bourbon whiskey and the production of rum from molasses. The plants from which these wastes originated were in a town where the sewage from a population of 12,373, amounting to an average daily flow of 1,469,000 gallons per day, is disposed of through works consisting of bar screens, eight plain sedimentation tanks, each having a capacity of 225,000 gallons, and 26.23 acres of sand filters for intermittent filtration of the sewage after sedimentation.

The distillery wastes caused objectionable conditions from odors near the sewage disposal works, a large amount of objectionable sludge to be disposed of, the deposit of a yeast-like film over the surface of the filters and an effluent having a very objectionable odor. It was estimated that the quantity of these wastes was between 18,000 and 25,000 gallons per day. The experiments consisted of filtering the wastes with the domestic sewage of the city of Lawrence through a small filter 3½ feet deep, containing sand having an effective size of 0.25 mm., at a rate of 50,000 gallons per acre per day. The applied sewage contained at first 1.33 per cent distillery waste and later 2.66 per cent of this waste. Inasmuch as the filter became clogged after three weeks' application and the sand of the experimental filter was of better quality than the sand at the municipal sewage treatment works, the Department of Public Health recommended that the distillery wastes be treated at the distillery and that the wastes discharged to the municipal sewers should not contain suspended matter in larger proportions than 500 parts per million. With the assistance of the office of the State's Attorney General the following stipulation was received from the superior court:

> And now comes the respondent, Clinton Distilleries Corporation, and stipulates that its agents and servants will not discharge industrial wastes from the distilleries processes carried on at the Clinton Distilleries Corporation plant in Clinton until the

suspended matters are reduced to not over five hundred parts per million, and until a method has been arranged or put in effect to so reduce the suspended matters, the present connection from the Clinton Distilleries Corporation plant to the Public Sewerage system shall be discontinued.

The wastes from the production of rum consisted chiefly of diluted molasses from which the sugar had been converted to alcohol and distilled off. It was estimated that these wastes amounted to 15,500 gallons per day which is about 1 per cent of the average daily flow of sewage to the municipal sewage disposal works and were discharged over a period of 10 to 12 hours. These wastes were found to be susceptible to treatment by chemical precipitation.

In order to determine the effect of these wastes upon the municipal sewage filters if discharged into the public sewers, a small filter 3½ feet deep filled with sand of an effective size of 0.25 mm. was operated at the Department's experiment station at a rate of 50,000 gallons per acre per day by applying to this filter the Lawrence city sewage containing 1 per cent distillery waste. In spite of the large amount of organic matter present, the effluent from the filter was of good quality and stable.

Elastic Webbing Wastes.—The experience of our Lawrence Experiment Station with elastic webbing wastes was in connection with the disposal of wastes from a factory in a town where there is no sewerage system but where it was necessary to ascertain the probable effect of such wastes on private disposal works. The manufacture of elastic webbing at this plant consists of the weaving of fabric around large threads of prepared rubber to make "elastic" of various widths. The wastes to be disposed of from this plant amounted to about 8950 gallons per day, of which 4300 gallons were domestic sewage from the plant and 4650 gallons were industrial waste liquor containing gum arabic, Swiss gum, spent dye, bleach liquors and wash waters. It was found that the gum arabic was very stable but the Swiss gum in passing through a settling tank containing domestic sewage was attacked by an acid fermentation causing foul odors. The dye and bleach liquors were inoffensive.

The only practicable way of disposing of the sizing wastes, which contained from 2 to 8 per cent of organic matter, was by evaporation and incineration. As these wastes amounted only to 150 gallons per day, this method of disposal was proposed. A mixture of two parts of the other wastes with one part of domestic sewage gave satisfactory stable effluents with no clogging when applied intermittently to sand filters at the rate of 25,000 gallons per acre daily and to a trickling filter when operated at a rate of 500,000 gallons per acre daily. The sand filters used in these experiments were 3½ feet in depth with sand of an effective size of 0.25 mm. The trickling filter was 3½ feet deep and consisted of a good quality stone which would pass a 1½-inch ring but be retained on a ¾-inch ring.

Dye Wastes.—At the request of the officials of one of our large industrial municipalities, the Department of Public Health in 1931 ex-

perimented with and advised as to the disposal of certain dye wastes into a municipal sewerage system where the sewage amounting to about 563,000 gallons per day was treated by plain sedimentation and by filtration through sand filters at a rate of 63,000 gallons per acre per day. It was desirable in this case to determine the probable effect of disposing of about 5000 gallons daily of spent dye liquors with the municipal sewage, a proportion of waste to sewage of 1 to 112. These spent dye liquors were black, had a bicarbonate alkalinity of 2500 parts per million and a carbonate alkalinity of 500 parts per million. The filters used in these experiments were 3½ feet deep and contained sand having an effective size of 0.25 mm. They were operated for fourteen weeks. One of the experimental filters was operated at a rate of 63,000 gallons per acre daily with a mixture of Lawrence city sewage and the dye wastes in the proportion of one gallon of dye wastes to 112 gallons of sewage. Another filter was operated with a mixture in the proportion of 5 gallons of the dye liquors to 112 gallons of sewage. In these experiments, it was desirable to ascertain not only the effect of the dyes upon the operation of the filters but also the effect of the color upon the effluent of the filter. The sewage receiving .89 per cent by volume of the dye wastes had a color removal of 88.2 per cent in passing through the filter during the early part of the experiments, and at the end of the fourteen weeks the per cent of color removal was 75.2. The applied sewage receiving the 4.3 per cent of dye waste had a color removal of 42 per cent going through the filter.

Gas Wastes.—The work of the Massachusetts Department of Public Health in connection with the disposal of gas wastes with domestic sewage extended over the years 1932, 1933 and 1934, and the results are to be found in the annual reports of the Engineering Division for those years. The gas wastes used in the experiments of 1932 were from a plant in a city where the sewage is disposed of through works providing for plain sedimentation and for intermittent filtration of some 576,000 gallons per day through sand filters and about 2,726,000 gallons per day through trickling filters. The wastes from the gas plant in question consisted of 11,000 gallons of oil and tar separator liquor and 7000 gallons of ammonia-still liquor per day.

The waste from the oil and tar separator was a watery liquid comparatively weak but the waste from the ammonia-still contained phenols, thiocyanates, etc., and from 0.3 to 1.0 per cent of organic matter. It was not practicable to precipitate out the ammonia-still liquors by chemical precipitation and, as the phenol content was too great to sustain bacterial life, it was impracticable to treat these wastes by filtration without dilution with the domestic sewage. It was estimated that the volume of mixed waste to be treated was about 0.67 per cent of the volume of the domestic sewage reaching the municipal sewage disposal works. The two sand filters used in this study were 3½ feet deep and contained sand having an effective size of 0.25 mm. The first filter was used as a control and received the Lawrence city sewage at a rate of 50,000 gallons per acre daily and the second filter received increasing

amounts of the mixed gas wastes from ¾ per cent to 2.0 per cent of the volume of sewage. This filter also was dosed at the rate of 50,000 gallons per acre daily. After six months' operation in this manner, the second filter was then operated with only the ammonia-still liquor added to the domestic sewage, the amount of this liquor being at first 0.25 per cent and being gradually increased to 1.0 per cent of the volume of domestic sewage. The results of these experiments showed that the mixed gas wastes could safely be disposed of with the domestic sewage by sand filtration when this waste did not exceed by volume more than 1 per cent of the domestic sewage and when the sand filters were operated at a rate of 50,000 gallons per acre per day.

In 1933, the experiments were continued on gas wastes from which the ammonia had been removed by distillation. The waste after the removal of the ammonia contained from 0.3 to 1.0 per cent of organic solid matter in solution, was free from suspended matter, had a reddish-brown color and 0.5 per cent of this liquor imparted a decided color to the sewage. The experiments consisted of filtering the wastes through a sand filter, the applied sewage containing 0.5 per cent of ammonia-still liquor or about twice the proportion of this waste to the domestic sewage to be disposed of at the sewage treatment works of the municipality under consideration, and through a trickling filter to which also the applied sewage contained 0.5 per cent of the ammonia-still liquor. Sand filters used as controls were operated in addition with the domestic sewage without the addition of the gas wastes at a rate of 50,000 gallons per acre per day. A trickling filter was operated at a rate of 1,400,000 gallons per acre per day. The sand filter was 3½ feet deep and contained sand of an effective size of 0.25 mm. and the trickling filter was 10 feet deep and contained stone which would pass a 1½-inch ring and be retained on a ring ¾ of an inch in diameter.

At the municipal sewage treatment plant referred to, it is the practice to apply the settled trickling filter effluent to sand filters during the warmer months of the year. Accordingly, at our experiment station the settled effluent from the experimental trickling filters was applied to two sand filters for a period of a month. The sand filters receiving the effluent from the trickling filters were dosed at a rate of 75,000 gallons per acre per day in one case and the other received 225,000 gallons per acre every third day. The effluent from these latter sand filters was free from color. These experiments were repeated in 1934. It was obvious from the results of these experiments that the discharge of such gas wastes into the municipal sewers at a uniform rate in no greater proportions than 0.5 per cent of the domestic sewage would not unfavorably affect the disposal of sewage by sand filtration or by trickling filters.

Latex Wastes.—During the current year the Lawrence Experiment Station investigated the unsatisfactory settling in the Imhoff tanks and the clogging of a trickling filter of a town due to the discharge of rubber latex wastes into the municipal sewerage system from a rubber manufacturing plant in that town. At the time of the examination the sur-

face of the trickling filter was covered with a black substance which contained rubber to the extent of 1.8 to 5.8 per cent. It was found that the rubber company in question was engaged in the manufacture of rubberized fabrics using an adhesive which contained latex. The waste liquors from the plant consisted of the latex wastes and spent dye liquors. The latex wastes resulted from the washing of drums in which latex is received from the rubber plantations and from mixing tanks in the plant. The wastes contained in addition to the latex such substances as whiting, lithopone, accelerators and caustic soda. These wastes, which amounted to about 5000 gallons per day, were passed through settling tanks providing a limited detention period. The dye wastes, which amounted to between 2000 and 3000 gallons per day, did not have an unfavorable effect upon the municipal sewage treatment works and were discharged without treatment to the public sewers.

The work at the Lawrence Experiment Station showed that a trickling filter, a glass percolator one foot deep, filled with stone not larger than 1½ inches or smaller than ¾ of an inch, receiving a mixture of sewage and 0.28 per cent of the latex wastes at a rate of 1,000,000 gallons per acre per day, after four months' operation, deposited twice as much sludge on the filter as on the control filter receiving the sewage only. This sludge appeared to consist of rubber waste and an algae growth. These filters were operated to study the deposition of sludge only. No analyses were made.

Treatment of the latex wastes with a sufficient amount of sulfuric acid to produce an optimum pH of 3.5, followed by agitation by a mechanical mixer for ten minutes and settling for twenty-four hours, resulted in the separation and flotation of much of the solid matter, leaving a clear yellow liquid which could be drawn off at the bottom. This treatment did not appreciably reduce the B.O.D. of the wastes, although most of the colloidal matter was removed.

At the Lawrence Experiment Station a trickling filter 10 feet deep consisting of stone not larger than 1½ inches or smaller than ¾ of an inch was successfully operated at a rate of 1,000,000 gallons per acre daily with sewage to which was added 2 per cent of the clear liquid from the precipitation of latex waste by the above process.

A sand filter was also successfully operated with the same mixture at a rate of 50,000 gallons per acre daily.

The Department of Public Health recommended that the effluent resulting from the acid treatment be filtered through sand before it is discharged to the sewers.

Leatherboard Wastes.—The experiments at the Lawrence Experiment Station in connection with leatherboard wastes were primarily to determine the most practicable treatment to prevent an unfavorable effect on the water supply at one of the State institutions located below the leatherboard mill on the stream into which the wastes were discharged but also to determine the possible effect upon sewage disposal works which it is expected may soon be provided in the municipality. These wastes result from the processing of leather and paper scrap

into leatherboard, with the use of soda ash and acid orange and aniline dyes and large quantities of water. The excess water discharged to the river caused, at first, a reddish-amber color in the stream which soon resulted in a black, inky condition due to a combination of the tannic acid in the waste and the high iron content of the water of the river (2.0 parts per million).

The organic matter in the waste was found to be very stable, and attempts to treat the wastes by chemical precipitation and by digestion with domestic sewage sludge were unsuccessful although dilution with clean water, followed by filtration through sand, resulted in a reduction in tannin. The mixture of clean water and the wastes was not well adapted to purification by biological treatment but a mixture of 20 per cent of the wastes with domestic sewage was successfully filtered through sand. The sand filters used in these experiments, each of glass three inches in diameter, were three feet deep, filled with sand having an effective size of 0.25 mm. The first filter received the settled waste with 50 per cent of water from the public supply at the experiment station and was operated at a rate of 50,000 gallons per acre daily. The effluent showed a reduction of 82 per cent of the tannins, as measured by the volume of the effluent required to give the same intensity of black in water containing 2.0 parts per million of iron as the untreated wastes would give when added to water of this iron content. The reduction in albuminoid ammonia was 13 per cent and in oxygen consumed 31 per cent. The second filter was dosed with a mixture of 10 per cent of the wastes and 90 per cent domestic sewage and the applied liquor to the third filter contained 20 per cent of the waste and 80 per cent sewage. Both of these filters were operated at the rate of 50,000 gallons per acre per day, and the results indicate that sewage and 10 to 20 per cent of the leatherboard wastes in question could be filtered without interfering with the operation of the filters. One of the filters was operated for a period of several weeks at a rate of 250,000 gallons per acre daily with a mixture of 10 per cent wastes and 90 per cent water after sedimentation with a slightly better removal of tannins.

The main objection to any filtration of the leatherboard wastes was the increase in color of some of the effluents which in some cases was five times that of the raw water.

Paper Mill Wastes.—The experiments on paper mill wastes were conducted during the past year to assist the Department of Public Health in the consideration of certain plans proposed for a municipal trickling filter. These wastes were from the cooking of rag stock under steam pressure in the presence of caustic soda, soda ash or lime and from washing the cooked stock. They amounted to about 1.86 per cent of the daily volume of sanitary sewage to be disposed of and were made up as follows:

Cooker Liquor	10,100	gallons	per day
First Cooker Rinse	8,100	"	" "
Second Cooker Rinse	5,100	"	" "

The cooker waste was very strong, containing 7.9 per cent total solids and 3.6 per cent volatile matter.

Five small trickling filters were used in these experiments, each 10 feet deep and 10 inches in diameter, filled with crushed stone which would pass through a 1½-inch screen but be retained on a ¾-inch screen and were operated at a rate of 1,500,000 gallons per acre per day for a period of six months. The first filter, which was used as a control, received settled Lawrence city sewage, the second one received this settled sewage and 0.5 per cent of the mixed cooker and rinse wastes, the third received the settled sewage and 1.25 per cent of the mixed waste, the fourth, this settled sewage and 1.86 per cent waste, and the fifth, sewage and 2.5 per cent waste.

The wastes from the different mills under consideration were mixed in the proportion in which they were produced and allowed to settle for a period of one hour before being mixed with the settled sewage and applied to the filters. The effluent from the filter was permitted to settle one hour before being analyzed.

There was some color in the effluents from the dyes in the wastes from one of the mills but the results showed that nitrification was not seriously affected even when the wastes were added to the sewage in such large proportions as 1.86 and 2.5 per cent, and it was apparent that 1.25 per cent of the waste could be added to the sewage and filtered without increasing the B.O.D. and reducing the relative stability of the effluent to an undesirable degree.

Wool Scouring Waste.—In the year 1935 the Massachusetts Department of Public Health was called on to advise relative to the disposal of wool scouring wastes with the sewage of a town which is disposed of through Imhoff tanks and sand filters. These wastes amounted to 7500 gallons per day or about 0.6 per cent of the average daily sewage flow of about 1,250,000 gallons per day which is filtered at a rate of 46,000 gallons per acre per day at the municipal disposal works. To provide a safe margin, the Department's experiments provided for treating 1.0 per cent of the waste with the sewage.

The wastes which were from the usual type of scouring bowls were first settled for a period of twenty-four hours before being applied with the sewage to the filters, and for the first six months two sand filters containing 3½ feet of sand of an effective size of 0.25 mm. were operated at a rate of 42,000 gallons per acre per day. One of these filters was operated as a control receiving the domestic sewage only, while the other received the settled waste with the sewage. Two trickling filters containing 10 feet of crushed stone from ¾ of an inch to 1½ inches in diameter were operated for four months at a rate of 1,500,000 gallons per acre daily. As in the case of the sand filters one of these filters was operated as a control receiving sewage only and the other received the sewage with 1.0 per cent waste.

The effluent from the sand filter receiving the wastes with the sewage was of less satisfactory quality than that from the control filter but of good quality, and there was no clogging of the sand after a period of seven months. The effluent from the trickling filter receiving the

wastes was practically of the same quality as that from the control filter and actually had a lower B.O.D. and higher relative stability.

Yeast Wastes.—As early as 1909, the Lawrence Experiment Station was called upon to make experiments relative to the disposal of yeast wastes with domestic sewage, as the disposal of these wastes with the sewage was seriously interfering with the proper operation of the municipal sewage disposal works. Here the sewage from a population of about 5400 was filtered through sand filters before being discharged into the river. There were available for filtration of the sewage seven sand filters having a total aggregate area of 3.95 acres. It was estimated that the yeast output of the plant amounted to about 50,000 pounds, each month, together with small quantities of white vinegar and that the wastes to be disposed of amounted to about 16,000 gallons per day or about 5½ per cent of the average daily flow of municipal sewage.

The raw product used at these works consisted of molasses and barley malt, and the molasses diluted with water was mixed with certain proportions of a mash of the barley malt and water which after proper stirring and heating was drawn off into fermentation tanks. After the process of fermentation and the yeast had settled out the supernatant liquor was drawn off and either used in the manufacture of vinegar or discharged to the sewer. In the making of the vinegar this liquor was pumped to a still and the heavy residue from the still, amounting at times to 2500 gallons per day, was discharged to the municipal sewers. The yeast which was removed from the fermentation tanks with a certain amount of the liquor from this tank was pumped to washers where it was diluted with water and allowed to stand. After the yeast settled out, as much of the supernatant liquor as was possible was drawn off and new water was added for the second wash. This process was continued until as many as five to six washings had taken place, in each case the supernatant liquor being drawn off to a tank to be discharged to the sewer or used in part for the distillation of vinegar.

Other wastes from the plant consisted of lime water used in washing out the tanks, press liquor and water used in washing the press cloths, floor washings and cooling water. In addition there was a small amount of dry residue from the barley malt mash tank which was sold to farmers. The wastes to be disposed of at times were made up as follows:

Yeast liquor ("beer")	3,500	gallons	per	day
*Heavy residue in vinegar still	2,500	"	"	"
Primary wash	1,500	"	"	"
First wash	2,200	"	"	"
Second wash	2,200	"	"	"
Third wash	2,200	"	"	"
Fourth wash	2,200	"	"	"
Fifth wash	2,200	"	"	"
Total	18,500	"	"	"

* Once or twice a week.

In experimenting with these wastes, three sand filters each 3½ feet deep, containing sand having an effective size of 0.25 mm., were used. The first filter for a short time received the mixed wastes from the plant in their correct proportions and was operated at a rate of 25,000 gallons per acre daily but after a short time the applied wastes were in the proportion of one part of the still liquor to two parts of the yeast washings, and the rate of filtration was increased to 50,000 gallons per acre daily. As the wastes became acid upon standing, lime was added before application to the filter. This filter operated about one month but practically with no other results than that of a strainer, which provided about 50 per cent removal of the organic matter.

The second filter was operated in the beginning at a rate of 50,000 gallons per acre per day with a mixture of 95 per cent of municipal sewage and 5 per cent of the wastes in the proportion of their production. After two months, the per cent of wastes was increased to 7½ per cent. This waste for a short time received lime but the lime treatment then ceased. Good nitrification took place in the filter receiving this 7½ per cent mixture of waste but attempts to increase the percentage of wastes resulted in reduced nitrification. A filter containing 3 feet of clinkers, receiving this mixed waste and sewage, showed practically no purification. Also, purification beyond the removal of about 50 per cent of the organic matter was unsuccessful when this 7½ per cent waste was mixed with sewage sludge from a septic tank after a long period of rotting. Further experiments showed that, by settling these wastes for a period of two hours, about 25 per cent of the organic matter was removed and that, by straining the supernatant liquor from the settling tank through 3½ feet of sand of an effective size of 0.26 mm. at a rate of 100,000 gallons per acre daily, 40 to 50 per cent of the remaining organic matter could be removed.

During the year 1935, the Department experimented with wastes from another yeast plant where the sewage of the municipality, amounting to about 649,000 gallons daily is filtered after plain sedimentation through sand filters at a rate of 72,000 gallons per acre daily. The concentrated wastes from this latter yeast plant amounted to about 7000 gallons daily, or 1 per cent of the amount of the domestic sewage.

Because of the already loaded condition of the sewage disposal works, the Massachusetts Department of Public Health recommended against the disposal of these wastes into the sewers.

Massachusetts for many years has been an industrial state with many diversified industries. With this in mind the Legislature in 1886 adopted an act which has been revised but slightly and which now appears as General Laws, Chapter 111, Section 17, as amended by Chapter 340 of the Acts of 1937. This act provides that the Department shall consult with and advise persons engaged or intending to engage in any manufacturing or other business whose drainage or sewage may tend to pollute any inland water as to the best method of preventing such pollution, and that it may conduct experiments to

determine the best method of treatment. The act also provides that no person shall be required to bear the expense of such consultation, advice and experiments. In accordance with this act, the Department as indicated has carried on many diversified experiments on the disposal and treatment of industrial wastes. Much of the earlier work was reported in the Annual Report for 1909. The recent annual reports, while somewhat curtailed in volume, have nevertheless contained considerable information relative to the treatment of industrial wastes including the effect of such wastes on various methods of sewage treatment. Work is now under way in summarizing and indexing the results of the various experiments at Lawrence and presumably this summary and index will be available at no far distant date.

A SURVEY OF RECENT DEVELOPMENTS IN THE TREATMENT OF INDUSTRIAL WASTES*

By Willem Rudolfs

Chief, Div. Water and Sewage Research, New Jersey Expt. Station

A review of trade waste treatment as presented in the literature during the years 1932–34 was given as a chapter in the book "Annual Survey of American Chemistry" for 1934, and also published in This Journal (1) and was almost exclusively confined to the treatment of liquid wastes from industrial plants. Beginning where this review ended, it is the intention in the present discussion to bring the literature up to date, to present briefly new developments and to emphasize those methods which appear to have special merit for individual wastes or are capable of being utilized in a broader field. Again a brief discussion of the more important patents has been included.

Many of the treatment devices and chemicals employed depend upon the character of the waste and need modification when adapted for similar wastes produced within the same group of industries. In many instances attempts have been made to utilize or modify well-known existing sewage treatment processes for the treatment of a particular waste. Frequently such efforts are successful, but a number of instances are known where such an effort resulted in failure or extreme high cost. Sewage treatment has grown up along lines of preventing or minimizing health hazards and only later general stream pollution and nuisances factors became important.

Although considerable work has been done during the last few years in connection with industrial waste treatment, and in spite of the fact that many industrial wastes may be treated and rendered innocuous, only a beginning has been made in this country.

In presenting this survey the information available for the period September, 1934 to August, 1937 has been grouped on the basis of types of industrial wastes. A brief summary is attached dealing with the more important trade waste surveys made in connection with stream pollution.

Gas and Phenol Wastes

A series of reports on the biochemical oxidation of gas works liquor have been published by Key and Etheridge (2). The difficulty of treating gasworks liquors is due to the presence of phenols, higher tar acids, thiosulfate and thiocyanate in spent liquors and the same plus sulfide in ammoniacal liquors. On non-sectional trickling filters these substances when diluted with sewage were destroyed completely by bacterial action. Thiocyanate could not be dealt with when first ap-

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plied to the bed; evidently specialized bacteria must first develop. With sectional filters phenol was rapidly oxidized, disappearing completely long before the sewage with which it was mixed was purified. Experiments with activated sludge gave an order of increasing difficulty of oxidation of phenol, thiosulfate, catechol, thiocyanate and sulfide. Sulfide had an adverse effect on the sludge. Additions of more than 5 per cent of spent liquors was detrimental. Sierp and Fransemeier (3), studying the biological decomposition of phenol, found that dilute acid solutions of phenol were readily destroyed. The ammoniacal decomposition of sewage used as media decreased with increasing concentrations of phenol. It was claimed by Sierp and Fransemeier that phenol concentrations up to 100 p.p.m. rapidly disappeared in polluted streams. This is important since phenols and gas wastes are harmful to fish, affect aquatic life, have a high oxygen demand and are apt to cause taste. Eldridge (4) has presented some results on phenol contents of several typical industrial wastes.

Key, Etheridge and Eastwood (5) state that the average ammoniacal liquors contain approximately the amount of CO_2 necessary to form bicarbonate with half of the "free" ammonia present. They propose a process whereby all the CO_2 and half the ammonia are removed by distillation and react to form bicarbonate. The remaining liquor is distilled to remove the remaining ammonia, which as a 5 to 10 per cent solution is used to extract CO_2 from the crude gas in scrubbers. All the CO_2 can be removed from the liquor with loss of only a trace of ammonia. Ammonia is 6.2 times as volatile in steam as phenol, but the presence of ammonia retards the distillation of phenols. CO_2 has a similar effect on distillation of ammonia. Not more than a small quantity of phenol can be removed when liquor is distilled to remove ammonia in the most economical manner (6). Dephenolating phenolic industrial waste liquors by the Pott-Hilgenstock process (of the Emschergenossenschaft), the Lurgi activated carbon and the I.G.F. trikresyl phosphate process are discussed in detail by Gösmeier-Kres (7) and the dephenolating plant at the Parthington Works of the Manchester Corporation Gas Department by Holton (8). The Farbenindustrie process is of considerable interest in connection with carbonization and hydrogenation of liquor effluents. The use of hot combustion gases passed through the waste waters, preferably those gases already used for drying moist materials for the removal of phenols from waste waters, is given in a supplementary patent (9). Sulfur dioxide may be added to the combustion gas (10). Phenols present in waste water from hydrogenation, distilling or low temperature coking processes, may be removed by treating the water with an adsorption agent such as activated carbon and than extracting this liquor with ammonia (11) or the phenol may be removed from distillation and coke plant wastes by treatment with water insoluble trialkyl or triaryl phosphates, worked up to a foam with inert gases (12).

Phenols can be adsorbed by activated carbons to the extent of 99.5

per cent. Rutovskii and Antropova (13) passed phenol wastes waters over peat charcoal at 40° C. For recovery, the phenol is distilled directly onto the carbon in amounts equal to 30 per cent of the water used. The carbon is regenerated by passing steam over it at 170–180° C. for 1 to 1.5 hours. A new process for removing phenol from waste waters is given by Chulkov (14). A phenol solution is treated with sodium hydroxide or calcium hydroxide and chlorine gas passed through. A resin is yielded. Air is passed through the solution to remove the excess chlorine and the liquid thereafter treated with activated carbon. A colorless, odorless, phenol-free liquid is obtained. The process can be applied (with minor modifications) to coal gas and tar products wastes. When H_2S, NH_3, SO_3, SO_4 or cyanide is present it is also removed by the process. The resin may be used in lacquers or paints or for a new synthetic resin. Lagergreen (15) reports that powdered Norite following alum removes about 75 per cent of the phenol content from the waste water. A Carbo-Norit process is also described by Ruf (14*a*).

To purify the waste water from a gas producer operated with brown coal, Voznesenskii and Aron (16) discharged the waste on three-stage slag filters. Some time was required to age the filters. Biofiltration has been carried out not only for purification but also to determine the extent to which the individual constituents of the gas were removed. In the West Riding of Yorkshire (17) evaporation and incineration with proper conditions afford a satisfactory and complete means of disposal without interference with purification. Chulkov, Parini and Chartova (18) describe the purification of water from salicylic acid and B-napthol plants. The waste water was purified with chlorine and calcium oxide followed by treatment with activated carbon. The treatment with activated carbon is said to decrease the oxygen demand of the material and practically remove impurities from the water.

Dairy Wastes

Biological methods for the treatment of dairy wastes have been in use for a number of years. They vary from disposal on land to activated sludge treatment. Laboratory and plant experiments on lath filters have been reported by Jenkins (19). A copious growth developed when a 1 per cent milk solution was passed through a lath filter and the effluent from this filter could be treated satisfactorily on a gravel bed. Crude milk washings were found to be amenable to treatment by a process of double filtration, or, as has been reported previously, by the activated sludge process. It is of interest to note that better effluents have been obtained by aeration of strong crude liquids for a long period than by the treatment of weaker liquids for a proportionately shorter time. Double filtration gave satisfactory results continuously under varying conditions and withstood occasional application of very strong liquid.

Studies to find methods of purifying the effluent from certain cheese factories indicated that trickling filters fed with a 10 per cent solution of whey, applied at the rate of 50 gallons per cu. yd. per day, accomplished a reduction of 90 to 95 per cent in B.O.D. (20). Neither replacement of part of the whey by skim milk nor decreasing the carbon-nitrogen ratio by the addition of ammonia, carbon or sodium nitrate had any adverse effect. Secondary biological filtration was relatively ineffective. Similar results have been obtained by Barrett (21). Halvorson and Smith (22) report treatment of creamery waste on trickling filters with revolving distributors to the extent of 85 to 90 per cent B.O.D. removal. The effluent from the trickling filters is then discharged into the city sewers and treated with the sewage. The method of treatment of creamery waste depends upon local conditions and varies considerably. Galligan and Levine (23) have described a number of possibilities to treat wastes by plain settling, with or without chlorination, followed by oxidation devices. In this connection Levine, Nelson and Goresline (24) have studied the effect of the nature of the filling material in filters and the dosing cycle on the purification of creamery wastes. Extremely high efficiencies were obtained with cinders, but they clogged quite frequently. Corn cob filters produced good results but shrank 35 per cent in depth and the efficiency decreased sharply after some months of operation. Excellent results were obtained with gravel and broken tile as well as with special ring packing. The dosing cycles did not affect the efficiency of cinder filters, but on quartzite the efficiency decreased as the length of the cycle increased. The more uniform the rate of runoff the more nearly the peak efficiency was reached for a given load. Experiments on design and operation of typical milk waste on filters have been made also by Eldridge (25). Low pH values of less than pH 4 almost completely inhibt the activity of the organisms in filters (26). Sodium lactate is very toxic to anaerobic bacteria but complete oxidation can be accomplished by sprinkling filters. A discussion of the progress in milk waste disposal has been given by Roberts (27) who described different types of milk plants and their methods to recover by-products such as chicken feed, milk sugar, calactate and sodium lactate. Another discussion of the disposal of dairy waste together with German regulations relative to waste disposal is given by Dyrenforth and Richter (28). They discuss the use of settling tanks, grease traps, sludge digestion, chemical treatment, contact beds, irrigation and seepage methods. In many instances creamery wastes interfere with regular operation of sewage treatment plants (29).

Brewery, Distillery and Fermentation Wastes

The discharge of brewery and distillery wastes into streams and watercourses is an important problem in certain sections of the country and are considered in certain states the major industrial waste problem (30). Hog feeding of distillery slop has been practiced and where hogs

could be confined to isolated areas this method is said to be successful. Screening most of the suspended solids of the slop and converting it into dry cattle feed may be practiced as partial treatment of the waste (31). It has been found that about 10 per cent of the solids could be recovered at a profit by screening and an additional 50 per cent disposed of economically as a liquid cattle food. The statement is made that complete recovery by evaporation is economically practicable in any but the smallest plants.

There are some studies reported (32) which show the toxic effect of distillery slop on the aquatic life of streams. Sedimentation produces relatively little improvement in wastes from breweries, starch manufacturing, etc., because most of the organic matter is in a state of true solution and cannot be removed by coagulation. Aerobic methods of treatment have been used, but loading limits for good results are low, and the sludge produced settles poorly. In addition the high acidity caused by the souring rapidly developed in these waste seriously interferes with aerobic processes. Anaerobic digestion is frequently unsuccessful for the same reason unless the material is diluted or other methods for acid control are used (33). Buswell has described a digestor, consisting of a perforated horizontal drum submerged in a covered tank, for handling fibrous wastes. The material is fed into the tank through a tube in the side. Digestion is conducted at a high temperature and the degree of purification is said to vary from 70 to 90 per cent. The liquid waste from the digestor can be discharged on trickling filters when diluted from 1 to 5 times with trickling filter effluent (34). A patent to utilize thermophilic organisms with proper pH control for this type of waste has been issued (35). A description of an apparatus in which the waste waters are treated with ferric sulfate and carbon dioxide and then distributed over beds composed of broken tile and clinker, where the material is subjected to very intense aeration, has been given by Raux and Maringe (36).

Malthouse waste treatment studies made in Wisconsin (37) indicate that this waste can be successfully treated by screening and properly designed trickling filters. A reduction of 90 per cent of the original B.O.D. is possible. In recent years the purification of waste water from larger yeast plants, usually from molasses as raw materials, has become a serious problem, but purification studies made on several Danish and Swedish plants (38), utilizing anaerobic fermentation followed by trickling filters, are said to be successful. The gases produced by the digestion are used for heating purposes. The Solvay Company (39) patented a process to sterilize the fermentable matter by means of hypochlorous acid. Moreau and Aubertin (40) state that brewery waste waters can be effectively purified by treatment with milk of lime and ferric sulfate, followed by decantation and intermittent filtration through coke. Intensive aeration is necessary and during filtration an alkaline reaction must be maintained. In some instances the solids separated from the associated liquid are placed in a dryer while the

liquid of the sludge is digested, using the gas produced for operation of the dryer (41).

Studies on chemical precipitation of distillery waste by Hoover and Burr (42) indicated that coagulation is not economically satisfactory when lime and iron or aluminum salts are used. Dilution of the material and filtration through deep trickling filters built of laths is said to produce 90 per cent reduction in B.O.D. with clarified grain waste, or relatively clear apple-brandy or molasses alcohol wastes. For treatment, these wastes must be diluted to obtain a 5-day B.O.D. below 2000 p.p.m. Intermittent sand filters are inefficient because of clogging and low capacity. Coke breeze of 1 mm. effective size is more satisfactory than sand. Adams and Birrer (43) conclude after considerable experimentation that chemical purification, aeration and expensive filters are not very useful for the purification of distillery waste. The authors advocate neutralizing the slops with milk of lime, and then application to meadow land. Dilution of distillery waste with an equal amount of fresh water, heating and addition of quicklime just before ebullition, is advocated by Ortega (44) as efficient treatment. The liquid is transferred to cooling containers having a large exposed surface, and is sprayed with an equal amount of cold water to effect precipitation of the solids. The solids are said to settle readily and may be used as fertilizer. Dikansky (45) patented a process of treating distillery waste with lead-subacetate; the supernatant is decanted and the residue filtered through coke.

Tannery Wastes

Studies made on sedimentation of tannery waste by Eldridge (46) led to the conclusions that lime wastes assist in the coagulation of the suspended solids and a portion of the soluble solids, and the lime wastes should therefore be treated together with other tannery wastes. The wastes should be mixed in a coagulation tank for about 30 minutes and settled for two hours. Chemical treatment of tannery waste by lime-ferric chloride process has been reported by Hubbell (47). The settled sludge is vacuum filtered at a cost of 28 cents per lb. of sludge, with a moisture content of 70 per cent. The sludge cake is used as fertilizer. The purification treatment of leather factory waste by removing the fat with air agitation and skimming has been described by Pauschardt and Furkert (48). The effluent is mixed with sewage and the solids digested.

Meat Packing and Cannery

Experiments on the coagulation of packinghouse waste made by Eldridge (49) indicated that chlorination was the most efficient coagulant and that the pH should be maintained below 6.0. Since efficient coagulation occurred only in acid medium, sodium and calcium hypochlorite and lime were not effective. Alum produced a poor floc and ferric chloride and ferric sulfates were not dependable. Levine, Nelson and Dye (50) found that packinghouse waste could be treated

in an experimental activated sludge plant unit operated on the fill and draw basis, but results with a full size plant were poor. The poor results are attributed to the marked fluctuations of the waste both in concentration and volume. Experimental filter units were operated to determine the efficiency of various filling materials and dosing rates with single and double filtration. By double filtration on a washable filter, followed by settling and filtration, a high degree of purification was obtained. The settled sludge and sloughings from the filter units were digested, yielding from 11 to 14 cu. ft. of gas per lb. of volatile solids in the sludge. A full-size plant of this type was built at Mason City, Iowa, and is claimed to give excellent results. Methods for recovery of waste from tanning and meat packing industries have been described by Van der Leeden (51).

Treatment of pea cannery waste by screening and the addition of iron sulfate and lime has been practiced in several cannery factories in Wisconsin (52). With kraut waste, alum and lime were used. The effluent was treated on trickling filters and results were greatly improved when the cannery wastes were aerated prior to treatment. A maximum of 20 per cent of cannery solids could be added to sewage sludge in digestion tanks. Some further information on the digestion of solids from pea and corn canning waste with sewage sludge are given by Warrick, Ruf and Holderby (53). Extensive experiments on the effect of different trade wastes on high and low temperature digestion were also made by Rudolfs and Setter (53a).

Sugar Waste

Wastes from beet sugar manufacturing constitute in certain localities an important problem. In Germany from 37 to 40 billion gallons of waste from 17,600,000 tons are produced. These wastes consist of soaking and wash water and the diffusion and press liquors. Spengler (54) advocates two methods for treatment. By settling the soaking and wash waters, from 80 to 85 per cent of the suspended solids can be removed, while 98 per cent removal is obtained by the addition of 0.01 per cent of lime. The press and diffusion liquors should be collected at the highest possible temperature for pulp removal.

The second method advocated, where the re-use of water is not possible, is to induce lactic acid fermentation and subsequent liming. This reduces the B.O.D. by 75 per cent, and the remainder of the liquid can be oxidized on a trickling filter. The acid fermentation results in a liquid, which, when discharged, attacks concrete. The same author describes a double fermentation process where in the first stage the acid concentration is built up until further bacterial activity is very slow. The material is then neutralized with lime. This neutralization causes the flocking out of most of the proteins present. The second fermentation then follows before the effluent is discharged. Szego (55) describes the Stenzel process where sugar beet wastes are subjected first to lactic acid fermentation at 45 to 50° C. and then to alcoholic fer-

mentation at 30 to 40° C. The effluent from this process must be greatly diluted before it can be discharged into a stream. In the Hildesheim process the waste undergoes lactic acid fermentation and then is made alkaline with lime. The materials is then fermented again and the effluent further purified by a biological process. The best results are obtained by the Nolte process where the waste undergoes butyric acid fermentation accelerated by activators; the liquid is then limed to a pH of 7.2–7.4 and subjected to anaerobic decomposition with the production of carbon-dioxide and methane. Finally the material is chlorinated and discharged.

The operation of an experimental plant has been reported upon by Eldridge (56) provided with equipment for coagulation, settling and biological filtration. The studies indicate that a removal of 90 per cent of the suspended solids and 35 per cent of the B.O.D. is possible with plain sedimentation. The Steffens wastes have considerable coagulating power and when mixed with combined flume and process water in factory proportions give an excellent floc and good clarification. Coagulation with lime increases the removals materially. Large volumes of sludge are produced. Biological filtration of the settling tank effluent was attempted during these studies and it was found that about six weeks were required for the development of the filter organisms. The rate of application must be less than 2 mil. gal. per acre per day. Biological filtration of process water would be needed only in extreme cases where the receiving stream is very small. Continued experimentation led to the conclusion that about 95 per cent of the suspended solids and over 50 per cent of the B.O.D. may be removed by plain sedimentation; when coagulated with lime slightly greater B.O.D. removals could be obtained, but not sufficiently better to warrant the quantity of lime required. A coagulation period of 20 min. and a settling period of 80 min. was as effective as 30 min. coagulation and 2 hours settling. For removal of grit a chamber at least 40 ft. long and designed to give the flowing velocity of one foot per second is necessary to handle from 100,000 to 150,000 gallons of waste per day. The use of the activated sludge process for treating the effluent is not possible on account of mechanical difficulties due to foaming. The use of biological filters is not possible or practical.

Blaffart (57) describes treatment of sugar beet wastes by dilution, sedimentation and trickling filters. The diluted waste is settled and about 96 per cent of the suspended solids removed. The effluent is passed through a gravel filter for partial oxidation. The effluent from this filter is then discharged to a second filter and the purification carried to a point where it will meet the requirements. When the first filter starts to clog the effluent from the settling tank goes to the second filter and the first filter is used for secondary treatment so that both filters are kept in operation.

Nolte, Meyer and Fromke (58) concluded on the basis of experimental work that sugar beet wastes can be treated by the activated sludge process after they have been fermented and neutralized with

lime. After 24 hours aeration the organic acids present were completely decomposed. The amount of substances which can be treated varied roughly inversely with the B.O.D. of the material. Haupt (59) describes the utilization of sugar and starch industries and the recovery of by-products. An investigation of the technical utilization of acid sugar beet wastes by Shidkow (60) shows that pectin adhesives can be obtained from the press liquor and several organic acids can be produced from the waste liquors.

Oil, Grease and Laundry Wastes

The elimination of any contaminating impurity from the water supply is important, especially when drought conditions are considered. Brines from oil fields are a serious problem. Two methods of disposal exist. One involves the impounding of the waste in reservoirs, with discharge into the stream at times of high flow and the other involves increasing the flow of the stream by impounded water. Neither method is entirely satisfactory. The construction of large storage reservoirs (61), disposal by evaporation and returning the brines to the underground formations comprise other methods.

Wilhelm, Schmidt and Ludwig (62) in a study of brine disposal, to prevent high chlorides in water supplies, come to the conclusion that return of brines to subsurface formations at present offers the most satisfactory solution to the problem. Wilhelm, Thorne and Proyer (63) conclude that impounding brines in ponds is not an effective method in western Kansas because of the character of the soil and nearness to the source of domestic water supply. They point out that where no attempt is made to condition the brine, the presence of large quantities of carbonates and sulphates may increase the rate of corrosion and produce large quantities of hydrogen sulfide. Taylor and Christianson (64), investigating methods for conditioning oil field brines into subsurface formation, by means of a pressure sand filter system and brine from a silicious lime stone formation, found that all the filter sands used were equally effective in removing suspended materials from the brine. A sand with an effective size of 0.59 mm. and a uniformity coefficient of 1.79 was the standard of all the sands studied. The flow of 2.5 gallons per minute per square foot of filter area was optional in regard to the economic condition, the duration of run and filter efficiency. Filtration affects the constituents of the brine by altering carbon dioxide deficiency. No dissolved oxygen is present when the hydrogen sulfide is very high.

Waste liquors containing grease or soap have been treated by a number of different methods. De Vreese (65) proposes to treat such waste with both calcium sulfate or calcium salt, such as $CaCl_2$, $CaSO_4$, calcium lactate and lime in sufficient quantity to yield a water containing calcium salt in solution and calcium hydroxide in suspension. The precipitate formed is removed by decantation, filtration or centrifugal treatment. Turf dust, sawdust, or other refuse may be added to the

separated sludge and the mixture dried and treated with solvents for fats, leaving a residue suitable for fertilizer. An excess of $CaSO_4$ is maintained at all stages in the waters which are to be purified.

Waste from margarine works receives preliminary treatment at the plant, where it is cooled, clarified and the fat removed, as described by Glaser (66). Soaps formed in the purification of the raw oils, the most objectionable constituents of margarine wastes, were decomposed with H_2SO_4. Considerable disintegration of sewers took place and cooling, aerating (to remove or oxidize H_2S) and neutralization of the free acid was sufficient to overcome all troubles. Sokolov (67) describes a simplified H_2SO_4 method of refining fats from waste waters from soap works. Günther (68) claims that fat recovered from such wastes can often be used profitably for textile refining purposes. The use of chlorinated air as an aid in grease removal in sewage or wastes containing high grease contents has been described by Faber (69) on the basis of experiments conducted over a short period.

Laundry wastes vary considerably in characteristics during each day's operation. This is because of the nature of the washing processes. The strongest values for B.O.D., oxygen consumed and solids are found in the suds from the first washing operation. Experiments made by Boyer (70) indicate that the waste must be adjusted to pH 6.4 to 6.6 by the addition of H_2SO_4 before chemical treatment can be attempted. After adjustment of the pH, ferric sulfate, ferric chloride or alum produced an effluent free from color and odor and reduced the B.O.D. from 85 to 90 per cent. The volume of wet sludge produced is large, namely about 4 per cent of the total waste. Boyer claims that laundry wastes may be applied to trickling filters at the rate of 1,000,000 gallons per acre per day, with a reduction of the B.O.D. of 70 to 75 per cent.

Textile, Dye, Paper and Alcohol Wastes

A rather complete survey of present knowledge concerning the treatment and disposal of waste waters in the textile industry was published by Geyer and Perry (71). In addition to a discussion of the effect of textile wastes on streams and a description of experimental work, a number of processes are described more or less in detail.

Laboratory experiments by Snell (72) on wastes from a plant in which silk and silk mixed goods were dyed showed that treatment of the waste with activated carbon, after diversion of the plant waste and boil-off, was more effective than coagulation in removal of color. The carbon could be used several times and reactivated. Organic solids were not noticeably reduced. Satisfactory results are reported in the use of activated carbon for the recovery of diphenylamine by Ruf (73).

The waste from the cellulose and paper industry presents a variety of problems frequently changing with the kind of pulp and the processing. The filtration of dye house and wool scouring waste after mixing with fibrous material is described in a patent by Wright (74).

Steinschneider (75) claims that with screens of sufficient fineness and a plant of adequate size the fiber content in the waste can be held down to 12 to 15 p.p.m. In general, sedimentation is unnecessary as the additional degree of purification is not justified by the cost. The recovery of various waste liquors and particularly the utilization of sulfite waste liquor is discussed by Steffens (76). Recovery of tannins, use as artificial fertilizer, binder and fuel have failed, owing to limited outlets available for disposal, but seepage is not recommended. Decomposition in the presence of phosphorous and nitrogen compounds has been largely successful in reducing the oxygen absorption of sulfite wastes. Steffens points out that no comparison can be made between the B.O.D. of domestic sewage and the oxygen demand of sulfite waste.

Merryfield (77) has discussed the very difficult wastes resulting from manufacture of sulfite pulp. The best promise of ultimate solution of the problem appears to lie, according to this author, in the utilization of the wastes for by-products such as cattle feed, fertilizer and fuel. In comparisons of aerobic and anaerobic decomposition of sulfite wastes made in the laboratory, Benson and Partansky (78) show that under aerobic conditions the end products are carbon dioxide and water; while under anaerobic decomposition they are carbon dioxide and methane. Lignin is decomposed very slowly and its oxygen demand is reduced only one-fifth of that of the crude wastes. Under certain controlled conditions the wood sugars can be converted into butyric and acetic acid in two days with proper inoculation of special organisms. The acids can then be recovered by distillation, leaving only relatively stable lignin. A more detailed discussion is given by Partansky and Henry (79) of the anaerobic bacteria capable of fermenting sulfite waste liquor when made alkaline with lime to a pH of 9.6. The free SO_2 and part of the combined SO_2 were precipitated as calcium sulfite (80). The resulting liquor could be directly ammoniated to give a solid and liquid portion, both of which contained combined nitrogen. The solid material is suitable for fertilizer.

A flocculation method for treating whitewater by the method of the Adka Save-all has been given by Anspach (81). The use of waste materials from the cellulose and paper industry, in combination with flocculating agents, have been proposed by Wolf (82) for proper flocculation of solid materials in suspension. A foam is formed and after the flocculating agent is added industrial or domestic waste waters are mixed with the foam and passed into a sedimentation chamber. Paper mill and lye wastes, containing esparto or other washings with high oxygen demand, should be mixed with effluents from other parts of the paper mill containing oxidizing agents, or effluents or sludges from causticizing or bleaching (83). Snell (84) states that filtration of waste from manufacture of black and red fiber, made from newspaper and rope stock, is unsatisfactory. Sedimentation for 24 hours reduces the suspended materials materially.

According to Rinman (85) useful products can be obtained from lyes used for washing organic substances by concentrating the lye and

treating it with powdered barium oxide or barium hydroxide and calcium oxide. The BaO and CaO can be recovered by treating sulfite pulp waste lye in the above manner; acetone can also be obtained. Curran (86) describes the development of sulfite liquor recovery by precipitation (Howard Process). The waste liquors from the blow pits are treated with a precipitant under careful controlled conditions, with separation of calcium sulfite. This product goes back to the acid plant of the mill where it is used in the production of bisulfite of lime and re-used in cooking. The filtrate from this step is treated with lime, thereby precipitating a large percentage of the lignin. This residue is dried and sent back to the boiler plant for fuel. A third stripping action on the filtrate provides the materials used as a precipitant in the first step.

Treatment of waste liquors such as those of the alcohol, sugar and paper pulp industries by spray drying is proposed by Wagner (87). The liquor is sprayed into the upper section of a pre-heated furnace to effect substantially complete dehydration and partial distillation of volatile combustibles. Primary combustion air is supplied to the lower section of the furnace for the burning of the dehydrated residue. Gleason and Merryfield (88) come to the conclusion that at present no method of treating sulfite waste liquor has been shown to be applicable from an economical standpoint. The processes in use are Howard, Robson and the method of ponding and aeration. Ponding and aeration are less practical than the Paulson, Kuble or Badger processes, which involve evaporation and utilization of the residue as fuel or otherwise. Ponding and aeration under conditions of free aeration produce an appreciable decrease in the oxygen demand in the sulfite liquor. Mechanical agitation (forced convection) to be effective must be able to produce new surface exposure to the atmosphere.

For food wastes, trickling filters have proved fairly efficient if not overloaded. Fine screening and chemical treatment have been successful for kraut canning waste.

Mine Waste, Pickling Liquors

Holy (89) describes some unusual difficulties in treating mine water. The difficulties encountered are tastes and odors of woody characteristics, while the sodium sulfate concentration produces a saline taste. According to Schnitzler (90) the salty waste waters of a barite mine can be treated by separation of calcite with hydrochloric acid, producing an acid waste liquor high in $CaCl_2$. This is neutralized with lime so that the final effluent is a hard water. Clarification of colliery waste is described by Gifford (91) by means of starch and NaOH as a coagulant. Coagulation succeeds best at a pH of 11.0. He claims that it is highly advantageous to use frozen starch and imperative that the lime be incorporated with the water. Campbell (92) has patented a similar process where the starch is heated and use may be made of electricity. Campbell claims that best results are obtained with heated

starch. The possibility of recovery of sludges and other materials of value from the waste waters of coal mining industries are discussed by Wiegmann (93). The treatment of washery water, with particular reference to the practical aspects of flocculation, is discussed by Needham (94). If more than 30 per cent solids in washery water are present, troubles occur, in jigging from 15 to 20 per cent are desirable. Without flocculation, slurry underflow is difficult to filter. The important factor that governs the behavior of solids in washery water is size. Coal particles absorb clay from semi-colloidal suspension and retain the clay tenaciously. The use of electrolytes, especially CaO, is beneficial to washing results. The flocculation with other colloids is more complete. Electrolytes must produce insoluble compounds to produce an effect. Starch is an excellent flocculant due to the adhesion of pieces of jelly to the particles. In some cases the flocculation effect is enhanced when small amounts of electrolytes are added. Gelatin and glue solutions do not flocculate nearly so effectively as starch but readily flocculate stabilized clay. Flocculated solids can rarely be recovered by settlement alone, filtration is necessary.

Henry (95), inventor of the starch-alkali method used in Belgium and other places, claims that carbon filters effectively remove oil and suspended clay from waste waters. It is necessary, however, to precipitate the solids with suitable agents at a definite pH.

Studies on the treatment of waste liquor from the brass and copper industry made by the Connecticut State Water Commission (96) show that deposition and removal of copper depends upon a number of factors, the most important of which are space-velocity, *i.e.*, volume of liquor per hour per volume of chips in the treater, age effect on brass chips, grease, raw liquor and acidity. Small amounts of NaCl appeared to be necessary to give complete copper removal. With large quantities of iron salts, copper could be removed without the addition of NaCl. For good results, high acidity in the raw liquor is necessary. In the case of low acidity SO_2 was added. Changes in flow and lag period decrease the ability of the brass chips to remove the copper. Temperature is a factor, with an increased removal by use of air at higher temperature. Complete treatment of metal wastes requires final steps of neutralization and precipitation.

The cyanide waste from copper cyanide plating was treated by Eldridge (97) with H_2SO_4. The separation of chrome from chromate containing waste waters was attempted by Wittman and Wohlfart (98) by the addition of milk of lime or soda. If sufficient $NaHSO_3$ is added to change the color of the waste water from yellow to green the chromates can be separated. With large quantities of chromate, careful agitation and more bisulfite is needed, immediately followed by the additions of 10 per cent soda solution until the water becomes alkaline. The mixture was then heated to boiling for from 3 to 5 minutes.

A considerable number of papers have appeared in the literature during the last two or three years describing widely the treatment of

certain waste either along or in combination with domestic sewage. No attempt is made in this paper to summarize these contributions.

Trade Waste in Stream Pollution

The effect of trade waste on the pollution of streams varies considerably, but recent surveys have shown that it might be material and sometimes as much or more than the discharge of domestic sewage. The stream pollution survey made in New Jersey (99), indicates the importance of industrial wastes in respect to the quantities of wet sludge produced by the industries, amounting to over 700,000 tons a year as compared to 900,000 tons of sewage sludge. The estimated population equivalents for the industries amount to over 3,000,000 people or about two-thirds of the total population of the State.

The pollution survey made of the Mokelumne River in California by winery waste (100), indicating the character of the waste produced and methods of disposal, shows that the waste from five wineries had an average B.O.D. of 3500 p.p.m. and oxygen consumed values of 7800 p.p.m. The average population equivalent for 1935 was calculated to be 225,000 with a maximum of 384,000 at the peak of operation. During the winery seasons dead fish have been observed by numerous people and the runs of migratory salmon have shown an alarming decrease.

The results obtained by the West Riding of Yorkshire Rivers Board (101) shows that the greatest amount of pollution coming from the industries was due to textile wastes, with coal and mine industries running next. According to Langbein (102) the quantities of industrial and trade wastes discharged in streams in Germany are considerable and frequently more complex and more variable in composition than domestic sewage. Many sewage treatment plants in this country and abroad are handicapped by various industrial wastes, making the treatment of the mixtures more difficult. A number of studies are available dealing with the question of combined treatment of trade waste and sewage; frequently the amount of trade waste received determines the type of treatment employed. A number of reviews have been published by the different state engineers in *Municipal Sanitation* during the years 1936–1937. These reviews indicate not only the extent of the problem but frequently summarize the methods employed in different parts of this country. Calvert and Parks (103) determined population equivalents for nine types of industries at Indianapolis, accounting rather closely for the difference between the enumerated human population and the equivalent population calculated from the B.O.D. determinations and the sewage flow.

The possibility of using factory wastes for agricultural purposes has come up from time to time during the last few years especially in Germany. Grevemeyer (104) comes to the conclusion that in many instances trade wastes which have no value as fertilizer may frequently be used for irrigation if sufficiently diluted. Waste waters containing oils, fats or tars may be used for such a purpose if the oil is removed

or the fat saponified. Blew (105), discussing the economic importance of waste treatment to the industries, cites a number of cases where the industries have directly benefited by measures for alleviation of stream pollution. The examples cited deal with the paper industry, mercerizing, wool scouring, laundry, distillery, carbonization and storage battery. The annual reports of the Water Pollution Research Board (England) for the years 1934–1935–1936 contain considerable information on the extent of the trade waste problem in England and experimental work carried out to abate the difficulties.

A review of recent practices of trade waste treatment is not the place to contain speculations on future developments. The development appears to be in so many directions that it would be difficult to show definite trends, except that there is a tendency to take care of the waste in sewage treatment plants wherever possible, and that treatment of trade waste alone appears to become more and more complicated.

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Discussion of "A Survey of Recent Developments in the Treatment of Industrial Wastes"

(Willem Rudolfs)

By Charles R. Hoover

Hall Laboratory of Chemistry, Wesleyan University, Middletown, Conn.

In commenting upon a compilation and interpretation of the results of research investigations as complete as that presented by Dr. Rudolfs, little additional, definite published information is available to serve as the basis for such comments. Hence, reference to factual material will be necessarily brief and confined largely to unpublished results.

Dr. Rudolfs has stated that industrial pollution appears to be the weak link in the chain of general improvement of stream pollution. Another statement deserves additional emphasis, namely, "only a beginning has been made (in industrial waste treatment) in this country." This applies primarily to plant installations, but it also suggests that a wide variety of problems await solution in the laboratory. The amount of critical and original investigation needed can be justly said to be larger in comparison to sanitary wastes than the volumes, or even the population equivalents of such wastes would seem to indicate. It is more difficult to standardize treatment of industrial wastes in general, or even wastes from one plant, than treatment of sanitary wastes. In my limited experience it is possible to recall instances of originally successful industrial treatment processes being rendered inadequate, not by a change in the product, but by a change in one part of the manufacturing process, or a change in the method of preparing the raw material employed in a given plant. These constant changes in the concentration and properties of industrial wastes, logically indicate the

often mentioned but not too much emphasized need for adequate preliminary investigation and planning and adequate technical control for such disposal problems.

A few brief comments may be made on certain sections of the paper under discussion.

Gas and Phenol.—Some of the combined dephenolating and general purification processes mentioned by Dr. Rudolfs appear to have possibilities and should be further investigated. Since the importance of removing taste and odor producing substances from gas-waste liquors is accepted, processes ordinarily considered to be complicated or expensive may well become practically necessary. It is interesting to note the continued success of aeration and bio-aeration of coal gas wastes, at least in Great Britain. Well matured bio-aeration filters may reduce the oxygen consumed value of a settled coal gas waste as much as 80 per cent (1) during relatively short experimental tests. On the other hand as little as 0.5 per cent by volume of such wastes in sewage decreased the efficiency of experimentally tested activated sludge and percolating filters. However, in some sewage treatment plants both activated sludge and biological filters are apparently taking somewhat in excess of 0.5 per cent by volume of such wastes and discharging a final effluent of low B.O.D. and no objectionable phenol content.

Dairy.—A comprehensive study of the treatment of dairy waste is being directed by the Water Pollution Research Board of Great Britain with the cooperation of the dairy industry. Results of laboratory investigations described in the annual reports of the Board for 1935, show satisfactory purification by the activated sludge process with an aeration period of twenty-four hours, and by the use of percolating filters in series, periodically changing the order to prevent clogging. Large scale investigations at Ellesmere in Shropshire apparently confirm the laboratory results.

In common with others in this country we (2) have found that cloggling and odor nuisances can be prevented by re-circulating the effluent of a trickling filter, and that too long retention of milk or ice-cream wastes in equalizing tanks or in primary settlers apparently results in clogging and less effective oxidation in trickling filters.

Brewery, Distillery, and Fermentation.—The continued importance of evaporation processes, as indicated by new recovery plants which have been described in recent scientific meetings, should be mentioned in connection with distillery wastes. Such processes appear to be profitable to the large distiller, and, involving essentially complete elimination of liquid wastes, are very satisfactory to the public.

Sugar Waste.—From conversations with investigators in England last year, it appears that in the beet sugar industry much more re-circulation and re-use of press and diffusion liquors, than is generally accepted, can be employed to advantage. The chief difficulty with biological filters in the beet sugar industry appears to be the seasonal

nature of the industry and the length of time required for the development of active filter organisms.

Oil, Grease, and Laundry.—Biological oxidation of pure soaps in concentrations of 250 p.p.m. appears to be possible but may be incomplete and variable (3). Oxidation of the same concentration of soap in sewage is successful. Addition of phosphorus and nitrogen compounds is helpful. With laundry wastes we have found that the rate of settling of filter alum flocs in chemical coagulation is increased by the addition of calcium chloride.

Textile, Dye and Paper.—Chemical coagulation appears to remain the most effective method of decreasing both the color and the oxygen demand of such wastes. However, simple chemical coagulation is not always a cure-all for textile and dye wastes. Careful chemical control, applied to the numerous variables, may improve its efficiency but combination with other methods may be desirable. Soaps, fats, and oils may be reduced in concentration by preliminary, clarifying, or absorbing filters of combustible or, at least, replaceable ballast. Small amounts of color, remaining after treatment with a limited amount of chemical coagulant, may be removed as economically by activated carbon as by additional chemical dosage.

Investigations in this laboratory (4) for the State Water Commission of Connecticut have shown that most sludges from chemical coagulations can be re-used in suspensions, filtered mechanically, dried, and treated to recover iron and aluminum salts, but the last mentioned process is not economical with the present cost of corrosion-resistant equipment. Some air-dried chemical sludges may be burned advantageously with other solid fuel. In the chemical coagulation of paper wastes, such as white waters, the necessary control of pH can be secured by the simple expedient of using sodium aluminate or aluminium sulfate or mixtures of the two as required. The biological oxidation of cellulose by percolating filters to the extent of 70 per cent, and by activated sludge to 35 per cent, was shown to be possible several years ago (5). We have found that the oxygen demand of diluted kier liquors and mercerizing wastes, containing hemi-cellulose, can be reduced 70 to 80 per cent by trickling filters.

Mention should be made of the excellent results obtained by the rayon industry in the recovery of caustic soda by dialysis of caustic reject liquor pressed from wood pulp. Three patented dialyzers have been described recently: The Cerini (6, 7), Asahi (7) and Casey (8). In general from 90 to 92 per cent of the original 17 per cent caustic is recovered as an 8 per cent solution, and this recovery is reported as being indispensable in viscose manufacture. One type of dialyzer is reported to have been used to recover 25,000,000 lbs. of caustic soda in 1935. The membranes used, of parchmentized paper or cotton cloth, are reported to have a life of from one to nine months, and, in general, new membranes can be inserted without stopping the process. Experiments in this laboratory indicate possible advantages in applying dialysis to the recovery of caustic soda from waste mercerizing and

kier liquors, and also as a preliminary step in the purification of any waste containing valuable molecularly dispersed material.

Mine Waste and Pickling Liquors.—Since Dr. Rudolfs' summary was concluded, the strikingly beneficial results on stream acidity of sealing abandoned coal mines have been described by W. W. Hodge (9). We have found in laboratory (10) and plant scale experiments that plating room wastes, containing cyanides, can be disposed of in open areas by acidifying and exposing in shallow ponds, or by aeration through cinder beds. In residential or business areas precipitation as Prussian blue, while more expensive to carry out, may produce a saleable by-product.

Finally, may I presume to summarize a few of the apparent trends and future needs in the treatment of the wastes of industry.

First, the trend toward the combination of various well-known chemical, biological, and mechanical methods in the treatment of liquid wastes. For industrial waste, this means a revival of interest in biological processes. We seem to be recovering from the feeling that since some industrial wastes are stable or toxic, all are, and now recognize that many industrial wastes, if diluted to concentrations comparable with sewage, can be decomposed biologically. As one result of this trend we have not only the biological treatment of unmixed industrial wastes, but also the biological treatment of combined sewage and industrial wastes. As a second result, we have recognized the assistance of chemical and mechanical processes in the treatment of mixed wastes and sewage alone.

Second, increased attention to chemical and mechanical recovery processes, not as an independently profitable manufacturing operation, but as an attempt to lessen the cost of a general waste disposal program.

Third, the recovery or re-use of some of the more expensive industrial waste treatment materials, and the dialysis and electro-separation of recoverable colloidal and molecular material in both treated and untreated wastes.

Fourth, the possible advantages of thermophilic processes not merely to shorten the time of digestion of resistant industrial wastes, but to decompose substances less readily attacked under mesophilic conditions. For example, we have found that wool fiber is completely destroyed by thermophilic digestion, but not by mesophilic under the same conditions.

Fifth, the adsorption by chemical flocs or industrial or sanitary sludges of toxic components of industrial wastes as a preliminary to biological treatment.

Sixth, the need of improved and more rapid methods of analyzing industrial wastes. We are interested in (1) the Barcroft differential direct oxygen adsorption method of determining B.O.D.; (2) the rapid, preferably simultaneous, determination of carbon and nitrogen by wet combustion; (3) greater dependability of the oxygen-consumed test; and (4) more careful control of the dilution method of B.O.D. determination of saline or toxic materials.

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UTILIZATION AND DISPOSAL OF SULFITE WASTE LIQUOR *

By Kenneth A. Kobe

Asst. Prof. of Chemical Engineering, University of Washington, Seattle, Washington

Paper pulp is made from wood by four processes: (*a*) mechanical or groundwood, (*b*) soda, (*c*) sulfate or kraft, and (*d*) sulfite. In the mechanical or groundwood process the wood is reduced to fibers by the grinding action of an abrasive wheel. The pulp so formed is usually mixed with sulfite pulp and used for newsprint. The other three processes are chemical processes in which the wood chips are treated with a chemical reagent which will dissolve the lignin from the wood, leaving the cellulose fibers as the paper pulp. The soda process treats soft woods with a solution of sodium hydroxide to dissolve the lignin. The sulfate or kraft process uses sodium hydroxide and sodium sulfide as the chemical reagents and the resulting pulp gives the strong brown paper used for bags and wrapping. The sulfite process is used most extensively to produce a high grade white pulp. The chemical reagent used is calcium bisulfite and sulfurous acid made by treating limestone and water with sulfur dioxide.

Two Kinds of Waste Water

Pulp and paper mills have two kinds of waste water: (*a*) white water and (*b*) waste liquor. Water is the belt that carries the pulp fiber through the paper mill, finally to be filtered off in the paper machine. The water from the paper machine is called "white water" and still contains fibers too short to be filtered, hemicelluloses and other hydrolysis products of cellulose which give this effluent water a rather high oxygen demand. Some paper mills discharge all this white water, others re-use as much as possible, both to decrease water costs and pollution by the discharged effluent. However, total re-use of this white water is not possible, because of accumulated impurities and "slime" growths that give considerable trouble in white water systems.

Chemical Waste Liquors

The solution of the chemical reagent and the dissolved lignin from the wood is the waste liquor. In the soda and sulfate processes the chemical reagent used represents an appreciable cost that can be recovered by evaporating the solution, incinerating and dissolving out the soluble sodium compounds from the residue. Thus these two processes do not discharge a waste liquor to pollute water bodies. In the sulfite process the calcium bisulfite has combined with the lignin in such a manner that it is not possible to recover the chemical reagent. There-

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fore, mill practice has been to dispose of this waste liquor in the most direct manner, by dumping into the nearest body of water. This has created a considerable pollution of many inland waters and the problem has been recognized and studied by State Commissions and by the mills themselves. The Wisconsin State Board of Health has made an extensive survey covering a number of years through the cooperation of the pulp and paper mills (1, 2). Some of their results are given in Table I. The paper mills purchase pulp and make it into paper, so their waste effluent is comparatively small in volume and low in oxygen demand. The mills producing groundwood pulp are likewise low in

TABLE I.—*Waste Flow and Pollution Value of Pulp and Paper Mills*

No. of Mills		Waste Flow in 1000 Gal. per Ton Pulp		Pollution Value Population Equivalent Persons per Ton Pulp	
		1931	1934	1931	1934
		Paper Mills			
21	Av.	38.9	31.9	28.6	30.8
	Max.	116.7	83.1	79.0	158.4
	Min.	1.3	4.7	0.9	2.4
		Groundwood Pulp			
3	Av.	20.7	15.8	20.8	10.8
	Max.	28.1	33.2	32.3	21.0
	Min.	7.1	0.4	6.6	0.6
		Sulfite Pulp			
10	Av.	84.9	55.9	2630	1511
	Max.	225.6	104.3	6763	1905
	Min.	35.9	4.5	1255	896

$$\text{Population Equivalent} = \frac{\text{5 day B.O.D. (in lb./ton)}}{0.167}$$

pollution effect of their effluent. For these two types of mills the effluent is practically all white water. For the sulfite pulp mills the discharged effluent consists of both white water and waste liquor so that the pollution effect of this effluent is a hundredfold that of the other mills. Study of the disposal of sulfite waste liquor becomes imperative in order that the pollution may be minimized.

COMPOSITION OF SULFITE WASTE LIQUOR

Sulfite waste liquor contains all of the constituents of wood, other than the cellulose, combined with calcium bisulfite. A typical analysis (3) shows:

TABLE II.—*Composition of Sulfite Waste Liquor*

Results in Milligrams per liter	
Total solids	118,000
Ash	19,000
Volatile organic acids	5,300
Total sulfur (as S)	10,300
Lignin	61,500
Total sugars	20,100
Permanganate oxygen demand	110,000

For every ton of sulfite pulp produced, there is discharged approximately 2000 gallons of sulfite waste liquor containing ten per cent solids. More than half of the weight of the wood is discharged in the waste liquor.

Thus the chemist has at his disposal a solution of various materials that may be utilized in a number of ways. Just as coal tar became an important source of chemical raw materials, so too sulfite waste liquor may eventually become an important chemical raw material.

Many methods of disposal and utilization have been tried out by various mills. These methods will be discussed with respect to their utility for prevention of pollution and also for chemical utilization of the raw material.

PONDING AND AERATION

Some mills have attempted to decrease the pollution value of the sulfite waste liquor by storage in ponds and aeration before discharge in water bodies. These measures may improve the situation somewhat by oxidizing some of the easily oxidized sugars in the liquor, but this procedure is not a solution of the problem. Added problems are odor nuisances, percolation through the soil to underground water supplies, and accumulation of organic residues.

FERMENTATION

About 65 per cent of the total sugars in sulfite waste liquor are fermentable, so that a variety of products can be made by treating it with the proper organism. Baker's yeast is prepared by neutralizing the sulfite waste liquor, inoculating with yeast and allowing it to grow under carefully controlled conditions. Approximately 20,000 pounds per week are being produced in one plant in Nova Scotia and equipment to double this has been installed (4).

Alcohol is produced commercially in Europe by the fermentation of sulfite waste liquor. The liquor after fermentation has an alcohol content of 0.8 per cent which is recovered by distillation. Alcohol can also be recovered from the liquor after yeast growth, however, economic conditions in this country make it impossible to produce alcohol from sulfite waste liquor that can compete with alcohol from molasses.

The fermentation of sulfite waste liquor by other types of organisms found in sea bottom mud has been the subject of detailed study by Partansky and Benson (5).

Evaporation

The sulfite waste liquor obtainable from the wood digestion usually has a concentration of not more than 12 per cent solids. For many purposes this is too dilute a solution and cost of shipment becomes prohibitive so that evaporation must be carried out to give a concentrated solution.

A number of difficulties are encountered (6) in the evaporation, such as high viscosity, scale formation, corrosion, foaming and liberation of volatile substances. Despite these difficulties evaporation may be accomplished in multiple-effect tube evaporators constructed of corrosion-resistant alloy and usually operating under pressure in the first effect. With this type of evaporator the concentration of solids may be increased to 50 or 60 per cent. The use of spray driers, similar to those used in the dried milk industry, gives a light brown fluffy powder with about 10 per cent moisture, though the thermal economy of such a drier is quite low. A novel evaporator is in use by the Rainier Pulp and Paper Company at Shelton, Washington, in which the sulfite waste liquor is sprayed down a stack 120 feet high. Hot stack gases from the boiler plant are forced upwards in the stack and the sensible heat content of the hot gases is used to concentrate the liquor to about 50 per cent solids. This concentrated product is marketed as "Raylig."

Concentrated sulfite waste liquor is used principally as an adhesive. Most of the linoleum cements on the market have concentrated sulfite waste liquor as their base. It may also be used as a binder for briquetting coal. These uses are very small in their demand compared to the rapidly growing use of concentrated sulfite waste liquor as a road binder. In Sweden and New Jersey sulfite waste liquor has been used for several years for this purpose. In the State of Washington, "Raylig" has been supplied in increasing amounts to counties as an inexpensive binder for their secondary road systems (7). This use offers an ever increasing market, for sulfite pulp mills seem to be located at considerable distances from asphalt sources.

When a sufficient market is not available to absorb all the concentrated sulfite waste liquor, it may be burned. Concentrated sulfite waste liquor containing over 50 per cent solids is a liquid fuel that can be burned in a manner similar to fuel oil, though an ash problem arises. The liquid supports its own combustion and sufficient heat may be obtained from it to generate the steam used for the evaporation. Although this method is least efficient from the viewpoint of chemical utilization it is a very practical one from the viewpoint of pollution prevention.

Precipitation Methods

The Marathon Paper Mills Company at Rothschild, Wisconsin, have put into operation the Howard process (8) to treat the sulfite waste liquor from their mill. This process treats the acid sulfite

waste liquor with a milk of lime suspension which neutralizes the free sulfur dioxide in solution and precipitates calcium sulfite, which may be re-used in the acid making system. The further addition of lime precipitates the lignin from the solution. This ligneous material may be filtered off and utilized in numerous ways. The effluent from this process contains the carbohydrates in solution, though Howard claims the lime treatment has stabilized them against oxidation so that the B.O.D. of the effluent from this process will show a 75 to 85 per cent reduction from the raw liquor used in the process.

The lignin product recovered is a brown, flocculated precipitate which constitutes an abundant raw material for lignin products. A tanning extract, "Maratan," is produced from the lignin sulfonic acid existing in the precipitate. Synthetic plastics may be produced from the lignin material. Decomposition with alkali solutions yields phenols and vanillin, the essential ingredient of vanilla. These uses do not consume the entire output and the remaining lignin material can readily be burned as a solid fuel.

Precipitation with ammonia and the introduction of available nitrogen into the lignin gives a solid which has value as a fertilizer (9).

Summary

Sulfite waste liquor has the greatest pollution effect of any pulp or paper mill waste. The pollution may be prevented by utilization or disposal by methods other than discharge into water bodies. The present fields of utilization have been reviewed. Evaporation or precipitation give a material that can be burned as a fuel. However, a host of new chemical products may be developed by the complete chemical utilization of the lignin and carbohydrate compounds present.

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SEWAGE TREATMENT AND INDUSTRIAL WASTES IN THE FOX RIVER VALLEY *

By Samuel A. Greeley and J. W. Nemoyer

Greeley and Hansen, Consulting Engineers, Chicago

General

The Lower Fox River (Fig. 1) is a waterway about 38 miles long in Wisconsin, connecting Lake Winnebago with Green Bay. Lake Winnebago is a large, relatively shallow lake extending from Fond du Lac on the south to Neenah and Menasha on the north. Oshkosh is located on the west shore of the lake midway between Fond du Lac and Neenah, straddling the mouth of the Upper Fox River.

The cities of Neenah, Menasha, Appleton, Kimberly, Little Chute, Combined Locks, Kaukauna, Wrightstown and DePere are located along the banks of the Fox River. The city of Green Bay is located on the banks of the Fox and East Rivers, and along the shores of Green Bay, which is an arm of Lake Michigan.

The pollution of the Fox River has been under scrutiny by the Wisconsin State Board of Health for a good many years. In 1931, Greeley and Hansen were employed jointly by the several cities to report on the sewage disposal requirements of the cities lying between Neenah and Kaukauna along the Fox River. These cities now have a total population of about 60,000 people. Including Oshkosh and Green Bay, the sewage of approximately 140,000 people is tributary to the Fox River, these two cities having populations of about 40,000 each.

Paper making is the chief enterprise of the cities lying along the Fox River. The waste from the paper mills has been discharged directly into the Fox River and comprises a large part of the pollution. The population equivalent of sewage tributary to the Fox River is, at times, approximately 800,000 people.

Between Neenah and Green Bay, the Fox River has a fall of 170 feet and is controlled by fourteen dams. The normal minimum flow is 1,300 c.f.s. It will be seen from the hydrograph of the river that this minimum is not frequently reached. Since 1896, a flow of less than 1,000 c.f.s. has occurred only once.

Sewage treatment plants have been constructed or are in the process of construction at Green Bay, DePere, Kaukauna, Little Chute, Appleton, Neenah-Menasha and Oshkosh. All of the plants provide for primary treatment by plain sedimentation or chemical treatment, and for chlorination of the plant effluent during periods of critical flow in the river. This degree of treatment has been approved by the State Board of Health. It is estimated that some $5,000,000 will have been spent in the construction of sewage disposal projects in these communities, of which P.W.A. will have contributed about $2,000,000.

*. Presented at the Tenth Annual Meeting of the Central States Sewage Works Association, St. Paul, Minn., Oct. 22, 1937.

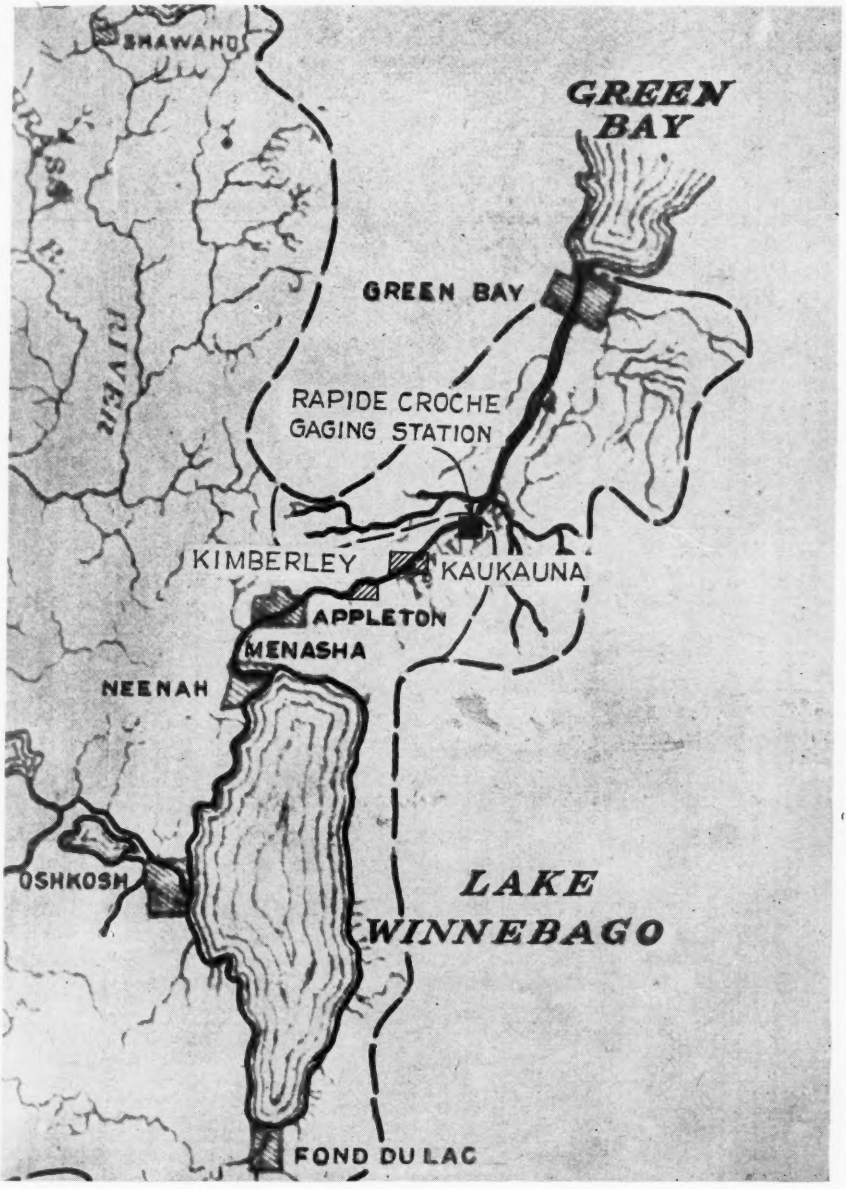

FIG. 1.—Fox River, Wisconsin.

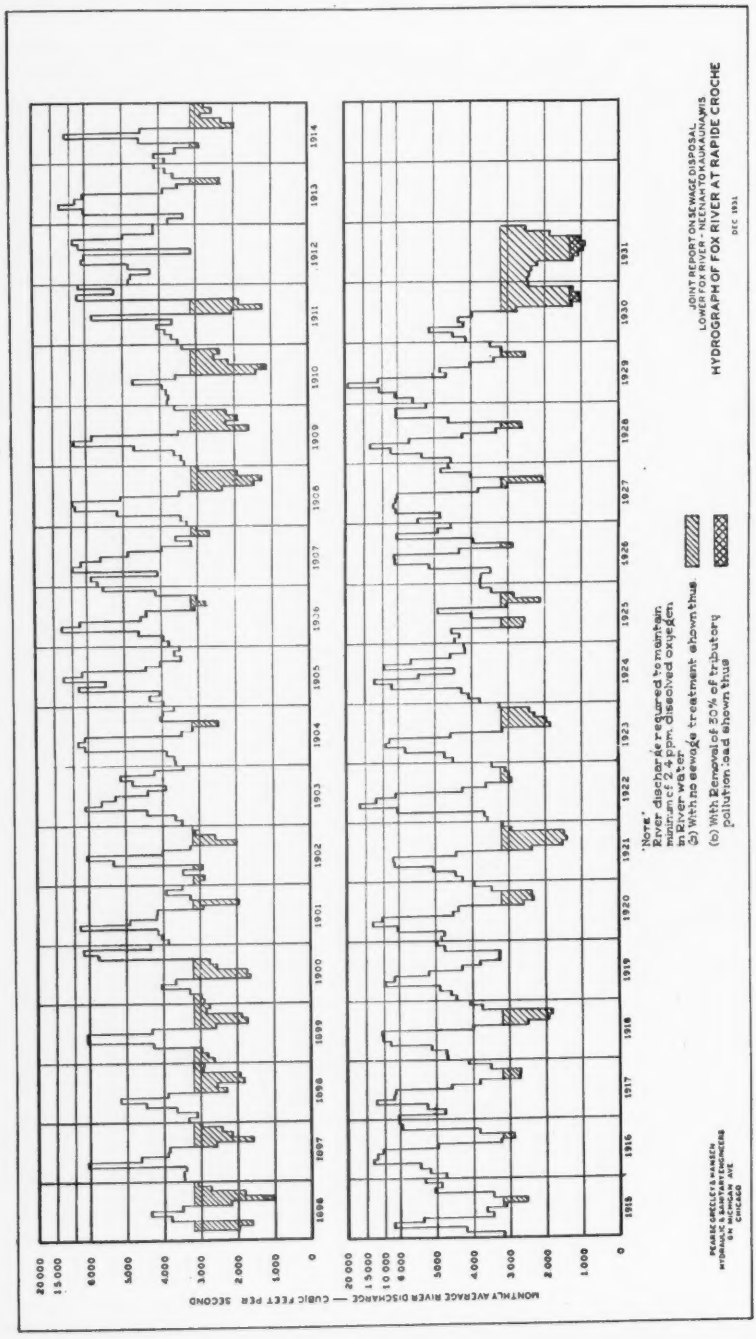
MONTHLY AVERAGE RIVER DISCHARGE — CUBIC FEET PER SECOND
20 000
15 000
10 000
9 000
8 000
7 000
6 000
5 000
4 000
3 000
2 000
1 000
0
1896 1897 1898 1899 1900 1901 1902 1903 1904 1905 1906 1907 1908 1909 1910 1911 1912 1913 1914
1915 1916 1917 1918 1919 1920 1921 1922 1923 1924 1925 1926 1927 1928 1929 1930 1931
Note:
River discharge required to maintain minimum of 2.4 ppm. dissolved oxygen in River water
(a) With no sewage treatment shown thus
(b) With Removal of 20% of tributary pollution load shown thus
JOINT REPORT ON SEWAGE DISPOSAL LOWER FOX RIVER - NEENAH TO KAUKAUNA WIS
HYDROGRAPH OF FOX RIVER AT RAPIDE CROCHE
DEC 1931
PEARSE GREELEY & HANSEN HYDRAULIC & SANITARY ENGINEERS 624 MICHIGAN AVE CHICAGO

FIG. 2.—Discharge records at Rapid Croche, 1896–1931.

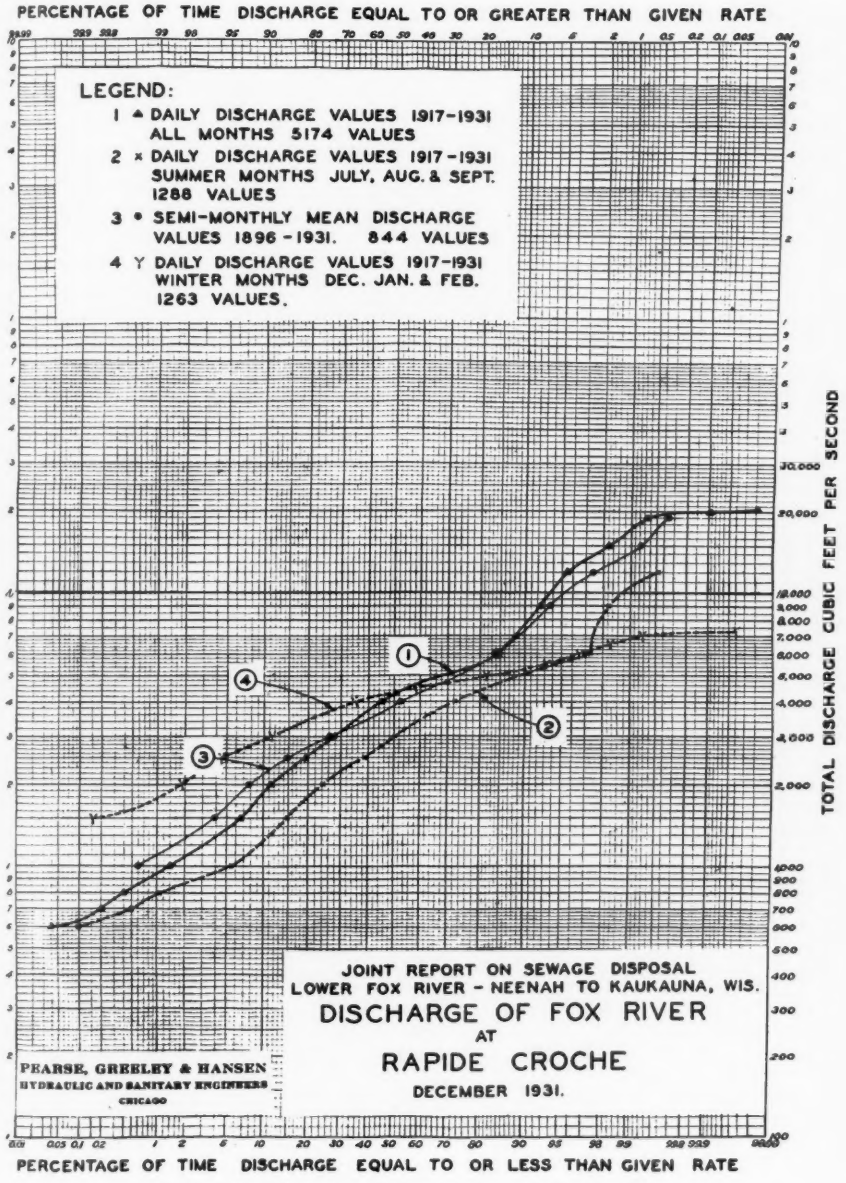
PERCENTAGE OF TIME DISCHARGE EQUAL TO OR GREATER THAN GIVEN RATE
LEGEND:
1 ▲ DAILY DISCHARGE VALUES 1917-1931 ALL MONTHS 5174 VALUES
2 × DAILY DISCHARGE VALUES 1917-1931 SUMMER MONTHS JULY, AUG. & SEPT. 1288 VALUES
3 • SEMI-MONTHLY MEAN DISCHARGE VALUES 1896-1931. 844 VALUES
4 Y DAILY DISCHARGE VALUES 1917-1931 WINTER MONTHS DEC. JAN. & FEB. 1263 VALUES.
TOTAL DISCHARGE CUBIC FEET PER SECOND
JOINT REPORT ON SEWAGE DISPOSAL
LOWER FOX RIVER - NEENAH TO KAUKAUNA, WIS.
DISCHARGE OF FOX RIVER
AT
RAPIDE CROCHE
DECEMBER 1931.
PEARSE, GREELEY & HANSEN
HYDRAULIC AND SANITARY ENGINEERS
CHICAGO
PERCENTAGE OF TIME DISCHARGE EQUAL TO OR LESS THAN GIVEN RATE

FIG. 3.—Time-discharge rates, Fox River, at Rapid Croche.

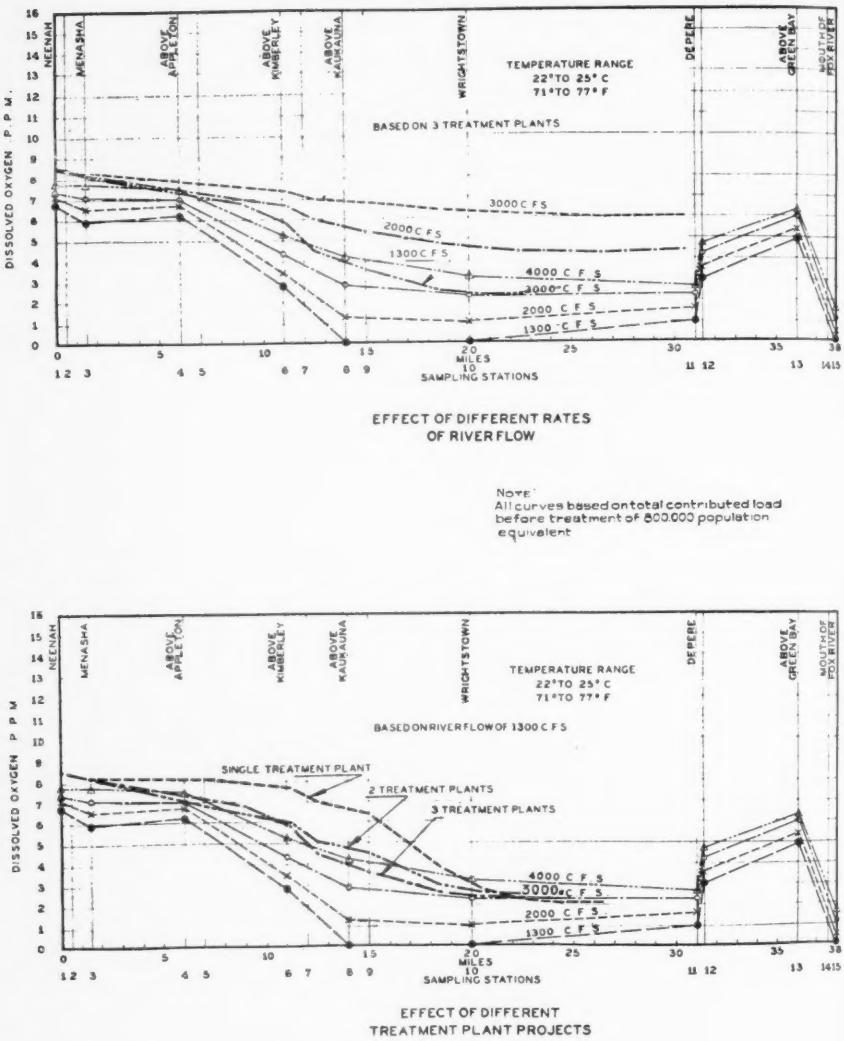

FIG. 4.—Dissolved oxygen profiles, Fox River.

We can speak in a more familiar manner concerning the sewage disposal projects at Kaukauna, Appleton and Neenah-Menasha as we have engineered these projects through the investigation, design and construction periods.

An interesting feature of our 1931 study was that of the river flows and oxygen balances in the Lower Fox River. The river discharge studies are shown partly in the attached hydrographic chart (Fig. 2) and time-discharge curves (Fig. 3). The results of the oxygen balance studies are represented, in part, by the accompanying dissolved oxygen

profiles (Fig. 4) which reflect data from fifty-five cross-sections and eight sampling stations along the river.

These studies indicated the desirability of independent treatment plants for the Neenah-Menasha, Appleton and Kaukauna communities and illustrate a basis for determination of purification requirements.

Kaukauna

Kaukauna has a present population of 6,800 people. The plant is designed on the basis of 7,500 people, plus an allowance for industrial sewage and has a rated capacity of 4.0 m.g.d.

The sewage treatment plant comprises a screen and grit chamber, a flocculation tank, two circular settling tanks, a chlorination tank, a covered sludge storage tank and control house, and a main building which houses the offices and laboratory, sludge and garbage handling equipment, chemical storage space and the building heating plant. The plant is located shortly downstream from the city, in industrial environment.

In view of the preponderance of paper mill wastes in the sewage to be treated, it was considered inadvisable to provide digestion equipment, and it was decided to install mechanical dewatering and incineration of the raw sludge. Facilities have been added to permit disposal of garbage by incineration at the treatment plant. The sludge dewatering equipment was furnished and erected by the Oliver United Filters, Inc., and incineration equipment by the Nichols Engineering and Research Corporation.

The treatment plant has just been placed in operation and is receiving at this time domestic sewage only. It is anticipated that industrial sewage will be taken into the plant about November 15th, concurrent with placing the sludge dewatering and incineration equipment in operation.

The plant has been designed to permit operation with chemical treatment, requiring only the addition of chemical feed equipment.

An interesting feature of the Kaukauna project is the large amount of intercepting sewer constructed in waterways. Kaukauna is very much cut by the channels of the river, the canal and innumerable mill races. To eliminate countless crossings of races and interference with industry, it was found desirable to construct much of the interceptor in the channel of the river. The river was quite shallow through this portion of the work and readily lent itself to construction of the sewers. Of 14,000 linear feet of sewers, 3,000 feet was in waterways.

The Kaukauna sewage disposal project represents an investment in construction of $304,000, of which $177,000 was spent for the treatment plant.

Appleton

The present population of Appleton is 27,000. The sewage treatment plant facilities have been designed for a population of 32,500 for structures which can be readily increased in number or size. The plant

is designed with a rated capacity of 10.0 m.g.d., of which 6.0 m.g.d. is estimated to be industrial sewage.

The plant comprises mechanically cleaned screens and grit chambers, a flocculation tank, two circular settling tanks, a chlorination tank, four covered sludge digestion and storage tanks and control building, chemical storage and feed building and a main building which houses the raw sludge pumping station, heating plant, office and laboratory; and open sludge drying beds.

The treatment plant is located on the south side of the Fox River downstream from the city, the site being unusual because of the rugged topography. The grit, flocculation and settling tanks, the chemical building and main building are located on the lower level of the site, on relatively flat land a few feet above high water level in the river. The sludge digestion and storage tanks and the sludge drying beds are located at the top of the bluff 40 feet above the low level of the site.

The plant has been in operation since February, 1937, and is treating about 3,000,000 gallons of sewage per day. This sewage is largely domestic. A few of the industries have been connected to the intercepting sewer, with many others to follow. The plant is removing 72 per cent of the suspended solids and 50 per cent of the 5-day B.O.D. by plain sedimentation. During the last month, the plant has been operated with chemical precipitation, using chlorinated copperas and lime. Records of operation with chemical precipitation are not yet available for presentation.

The sludge disposal portion of the plant is handling 7,000 pounds of dry solids per day. The gas production has been upwards of 30,000 cubic feet per day, the average daily production being 36,500 cubic feet during August which represents 13½ cubic feet of gas per pound of volatile solids removed from the sewage.

The plant lends itself readily to operation and is manned by a superintendent and four operators, with the part-time assistance of a chemist. Some use has been made of relief labor for sludge handling, maintenance of grounds, etc.

Construction of intercepting sewers in Appleton presented unusual difficulties because of the many river channels, canals and mill races. This difficulty was further increased by the very rough topography of the city along the river.

A feature of the interceptor is the river crossing which comprises an inverted siphon 950 feet long, composed of a double line of pipe 15 in. and 30 in. in diameter. The pipes are enclosed in a common concrete envelope, the top of which is 12 feet below standard low water level to accommodate navigation.

The Appleton sewage disposal project represents an investment in construction of $625,000, of which $297,000 was spent in sewage treatment plant construction.

Neenah-Menasha

The Kaukauna and Appleton projects were administered on the cities' part by the Boards of Public Works. Because of the very common interests of the cities of Neenah and Menasha, a special Act of the Legislature was obtained in September, 1935, to allow the cities to finance a joint sewage disposal system. The joint project is administered by the Neenah-Menasha Sewerage Commission which comprises two members each from Neenah and Menasha who are appointed by the City Councils and a fifth member who is elected by the four members so appointed.

The project was financed by the sale of general obligation bonds issued individually by the cities, the proceeds of which were turned over to the Sewerage Commission. Each city has shared equally in the cost of the sewage treatment plant, joint sewers, engineering and other overhead costs. Sewers designed for the collection of sewage from each city have been paid for by the city served. This arrangement required careful attention to cost balances as between the two cities.

The total population of both cities is at present approximately 18,000. The sewage treatment plant facilities have been designed for a population of 25,000 for structures which can be readily increased in number or size. The plant is designed with a rated capacity of 10.0 M.G.D., of which 6.0 M.G.D. is estimated to be industrial sewage.

This plant comprises a main building which houses the mechanically cleaned screens and screenings grinder; the sewage pumping station, a grit removal basin, a chlorination plant, a chemical feed plant and chemical storage space; sludge dewatering and incineration equipment, sludge pumping station, building and sludge tank heating plants, and offices and laboratory. In addition, there are a flocculation tank, two circular settling tanks, two covered sludge storage tanks and control building, chlorine handling equipment, a storage yard and a chlorination structure. The treatment plant is centrally located between Neenah and Menasha along the east shore of Little Lake Butte des Mortes.

In view of the preponderance of paper mill wastes in the sewage to be treated, it was decided to install mechanical dewatering and incineration of the raw sludge. The sludge dewatering equipment was furnished and erected by Filtration Equipment Corporation and the incineration equipment by Combustion Engineering Company.

Lack of railroad siding facilities at the plant site resulted in the design of the chemical plant for use of dry chemicals. All of the chemical machines are arranged for automatic and manual operation. When operating automatically, the machines are controlled by the sewage Venturi meter.

The requirements of treatment indicated the need for a greater degree of purification of sewage during the periods of extreme low river flow than would be afforded by plain sedimentation alone. Chemical treatment of the sewage during periods of critical flow in the river was

adopted as being lowest in cost and most certain to afford practical results of the many alternates considered.

This plant has been in operation since late August and is treating about 1,500,000 gallons of domestic sewage per day. It is anticipated that some of the industries will be connected into the intercepting sewer concurrently with starting operation of the sludge dewatering and incineration equipment late this month.

To provide good flexibility and to allow experimentation with the digestion of sludge, the plant design includes two 35 ft. diameter sludge storage tanks. These are both equipped with heating coils and floating covers. One of the sludge tanks has been in operation as a digestion tank during the last six weeks, operating with sludge from domestic sewage.

The structures and facilities are concentrated in layout, making for ready operation. The plant is operated by a superintendent, a chemist and four operators.

The cities of Neenah and Menasha are cut by two main channels of the Fox River, by a canal and mill races, which made for difficult sewer construction. Of approximately seven miles of intercepting and connecting sewers, two miles of sewer is constructed in waterways.

During the construction of the sewage treatment plant and trunk sewers, the cities of Neenah and Menasha have been separating storm and sanitary sewers. These projects were largely engineered by the individual cities, with the assistance of the engineers for the Sewerage Commission. The separation sewer projects were administered by the Sewerage Commission to give to the cities the benefit of P.W.A. financing, and the assistance of the engineering organization of the Commission in supervision over construction.

These projects have effected substantial separation of the sewerage systems, and upon their completion, the sewage tributary to the treatment plant will be largely sanitary and industrial.

The Neenah-Menasha sewage disposal project represents an investment in construction of $881,000, of which $375,000 was spent for treatment plant.

The Kaukauna, Appleton and Neenah-Menasha sewage disposal projects were all financed with the assistance of the Public Works Administration, from whom grants approximating 45 per cent of the project costs were obtained.

Operators' Reports and Suggestions

W. D. Hatfield

219 Linden Ave., Decatur, Illinois

PROBLEMS AND THEIR ANSWERS AT THE ONTARIO ACTIVATED SLUDGE PLANT *

By H. M. Ely, *Chief Operator*

In the operation of a sewage disposal plant, whether one of the newer types or one of the older, the operator is bound to meet with problems—some small, some large—and what may be a problem at one plant never bothers at another, while some are common to all plants.

In my paper I want to discuss three problems, one common to all plants as far as I can find out, and two that, so far as I know, have been problems for Ontario alone. First, the problem of bulking of the activated sludge. After watching and experimenting with my plant, I am convinced that there are two kinds of bulking: first, that caused by too little air compared to the amount of sludge carried, and, second, that caused by the addition of some foreign substance into the plant which destroys the equilibrium among the bacteria. At our plant the second kind has been brought about on several occasions by wastes from the "Orange By-Products Plant." In either case the problem resolves itself into one of specific gravity, and as you follow this discussion you will find why I arrive at this conclusion.

In the first instance, the cause is either negligence on the part of the operator or else comes from the desire of someone to conserve the power costs by cutting the air supply below the safety line, and the saving made at this time is paid out later in correcting the error. The remedy for this kind of bulking as a rule is not hard to find. Reduce your activated sludge and increase the air and the trouble generally clears in a day or two.

In the case of the foreign substance such as has been mentioned, the remedy is slow to act. In the winter of 1936 the City Manager informed me that the Rotary Club at Upland was to pay us a visit. Our effluent was very fine. Five days before they were to come we received a load of orange syrup from the "Orange By-Products Company." That immediately brought on a severe case of bulking. What to do! Time was too short to clear it by the addition of air and the reduction of the sludge and, after experimenting with various ideas, I decided to try adding fine clay soil to the tanks. On Saturday afternoon, two days before our guests were to arrive, I sprinkled six wheelbarrows of soil in the various aerators. Sunday morning I had as clear an effluent,

* Presented at the Ninth Annual Convention of the California Sewage Works Association, San Jose. Sept. 14, 1937.

with no bulking, as the plant had ever turned out. Four times since then it has been necessary to do the same thing, and it has never failed to clear up the problem.

I am satisfied in my own mind that, while there may be long names applied to the bacteria that cause bulking or that are found in the sludge at these times, the answer lies in the specific gravity of the mixture. It has ceased to be a problem at the Ontario Plant.

The second problem came with the month of January of this year. Those of you who reside in Southern California remember the smudge of January. The oil and the smoke in the air seriously affected the filter plates in our aerators, and the pressure on our air lines began to rise. Ordinarily, we use about 4.5 pounds of pressure, but during this period it rapidly advanced to 8 pounds. The increase meant increase of power and costs with lower efficiency. We were unable to find anyone who had had a similar experience and, after studying the problem it was decided to inject naphtha into the air line but we were unable to obtain any, so used aeration gasoline. We installed a four-quart tank on the main air line so that we could allow the gasoline to feed in slowly, using from three to four quarts per day, at the same time increasing the air to a maximum of two cubic feet per gallon. By the time the smudging was passed we had used a little more than ten gallons of gasoline and our pressure was back to normal. Our plates were as clean as when installed, and our problem had been solved.

The third problem arose because of the way one piece of equipment functioned. Our secondary clarifier always showed a slight disturbance at two different points in the tank, more noticeable when the flow was high than when normal. After studying the problem for some time, I concluded that if an additional baffle could be placed around the incoming flow in the center of the tank it would materially help. It was not possible to take the clarifier out of operation; so it was necessary to make the repairs while the flow was on. The flow in question entered the center baffle, which is 9 ft. wide, through a 12 in. pipe with a flared outlet about 3 ft. in diameter, opening towards the top and surrounding the central shaft. It was supposed to check the flow so as to make the distribution even over the entire clarifier, but it was failing in its work. I constructed a baffle of 16 gauge galvanized iron, which was placed on top of the flared outlet and extended within 3 in. of the surface of the water. In other words, it was a baffle within a baffle. Our clarifier now is without a current at any point and we are getting better settling of the activated sludge and a clearer effluent. The third problem has been solved.

SEWAGE PLANT OPERATION AT SANTA CLARA, CALIFORNIA *

By Albert J. Castro, Jr.

The sewage plant at Santa Clara consists of two hand cleaned bar racks, a Dorr clarifier, and primary and secondary separate sludge digestion tanks, both units also Dorr equipment. The plant serves a population of 7,000 people, two canneries, three packinghouses, a walnut packing factory, a tannery, and two small creameries. The average flow of sewage is 1,100,000 gallons per day during the fruit season, 756,000 gallons per day during the spinach canning and 560,000 gallons per day when the cannery is not operating.

The plant effluent is used for broad irrigation on a 236 acre surrounding farm. Its manurial value has been well shown by the fact that at one time on certain parts of the land only an extremely poor sugar beet, the size of a turnip, could be grown. After a year's watering with the plant effluent, beets with a diameter of from four to five times that of the original are now grown. Besides sugar beets, lima beans, alfalfa, and cucumber for seed are grown.

Of the above-mentioned trade wastes, the greatest difficulty arises from the handling of the cannery wastes; of secondary importance is the walnut packing waste, which is extremely high in chlorine at certain periods of the packing season. This season is fortunately only a month or so in length. For example, at one time after a four-hour contact period, the influent sewage had a residual chlorine content of 12 p.p.m. (ortho-tolidine method). As a result of this high chlorine content during the packing season the greater part of the bacterial action in our digestors ceased so that we had practically no gas production for twenty-five days during the month of October, 1936.

The plant has been in operation since June, 1936. The first problem confronting the operator was that of a satisfactory pumping schedule during the cannery season. Acting upon experiences obtained at other plants where fruit wastes are handled, an attempt was made to remove sludge from the sedimentation tank almost as rapidly as it was formed by pumping all the sludge from the clarifier every hour from 8:00 a.m. to 6:00 p.m. This method proved highly disastrous. The effluent from the secondary digestion tank, which returns to the clarifier where it is diluted before leaving the plant, contains a rather high volume of dissolved gases, which buoyed the sludge and caused it to rise to the surface of the clarifier.

The pH of the secondary effluent was 6.8 which soon induced an acid fermentation in the settling basin.

These two factors resulted in the rising of all sludge to the surface of the tank, where it remained. Large bubbles of gas from 3 to 6 inches in diameter formed on the surface of the tank. Besides defeating the operation of the clarifier and producing an extremely strong,

* Presented at the Ninth Annual Convention of the California Sewage Works Association, San Jose, Sept. 14, 1937.

sour odor which could be discerned at ½ mile down wind, our suspended solids and B.O.D. reductions were found to be decreased by 13 per cent and 30 per cent respectively. At one time the clarifier effluent was found to be 36 p.p.m. higher in B.O.D. than the raw sewage.

Pumping twice daily was attempted with the same result as above, because of the nature of the sludge.

Samples were taken of the influent sewage in Imhoff cones. It was found that practically complete precipitation of settleable solids occurred in the first ½ hour. At the end of two hours the sludge arose to the surface, buoyed by its own gases; some sludge remained at the surface while the remainder again settled to the bottom, only to rise again 20 minutes later.

Following these results, sludge was pumped from the clarifier every two hours from 8:00 a.m. to 6:00 p.m. for a total of 6,375 gallons; this procedure resulted in satisfactory operation. Odors are now at a minimum and although some dark colored sludge still exists on the clarifier surface it is not the strong, sour smelling, yellow sludge we had formerly.

We now obtain the following results during the fruit season:

	Raw Sewage	Per Cent Reduction
Suspended Solids	348 p.p.m.	57.1
Biochemical Oxygen Demand	765 p.p.m.	27.2
Oxygen Consumed	802 p.p.m.	61.3

When the cannery is not in operation most satisfactory results have been obtained by pumping sludge twice daily, once in the morning and once in the afternoon, for a total of 2,700 gallons. We then obtained the following results:

	Raw Sewage	Per Cent Reduction
Suspended Solids	381 p.p.m.	70.9
Biochemical Oxygen Demand	490 p.p.m.	42.5
Oxygen Consumed	446 p.p.m.	46.9

A hand cleaned bar rack with 2 in. openings was originally used for the removal of large solids. However this removed only a small percentage of sticks and rags, the remainder of which passing through caused a continual daily clogging of the screw-feed centrifugal sludge pump.

Upon the installation of a second rack also with 2 in. openings, a foot in front of the original rack, with bars so arranged as to be directly opposite the openings in the first racks, the clogging of the sludge pump has been greatly reduced.

In the operation of our digestion tanks we have as yet been unable to reach the recommended pH of 7.4 despite constant daily addition of lime during the first eight months of operation, with a total amount of 12 tons.

Due to mechanical trouble we have not been able to maintain a constant temperature of 86° Fahrenheit (30° C.) throughout this time.

Either this, the nature of the sludge, or the time which the digesters have been in operation may be the reason for the low pH of 6.8. The average temperature of our digesters throughout the past year has been 77° Fahrenheit (25° C.).

This year we by-passed the sewage for seven weeks for painting and repairing the plant, after which time we found the pH of the primary digester to be 7. A quantity of lime theoretically necessary to bring the pH up to 7.5 was added. After two days' operation the pH again dropped to 6.8. Our data on digestion when the cannery is in operation are incomplete at the present time; however when the cannery is not in operation sludge leaving the secondary digester has the following analysis:

	Per Cent	
Moisture	92.9	
Solids	7.1	
Volatile Solids	57.1	(Dry basis)
Fixed Solids	42.9	(Dry basis)

We have 46.1 per cent reduction in volatile solids through digestion, with an average gas production of 7,187.0 cu. ft. per day (1.10 cu. ft. per capita per day). We obtain 16.3 cu. ft. of gas per pound of digested volatile solids.

The average results of gas analyses during the past year were:

	Per Cent
Hydrogen Sulfide	6.21
Carbon Dioxide	25.66
Illuminants	0.0
Oxygen	0.0
Methane	46.75
Hydrogen	7.22
Nitrogen	14.16

The gas is used in the burning of rack wastes and in heating the digestion tanks.

Sulfur Reclamation.—The high hydrogen sulfide content has seriously corroded our boilers. A scrubber is to be installed which will remove this impurity. It is the belief of the author that with such a high percentage of hydrogen sulfide, in the future with an increase in the gas production, and no great change in the chemical composition, it may be commercially feasible to treat the resulting scrubber solution and obtain a sulfur sludge of a rather high commercial value. This sulfur sludge can then be put in wooden bins to dry; however, because of its colloidal state all the moisture is never thoroughly removed, so that it remains as a wet sludge.

Because of its extreme fineness it is particularly effective in the prevention of green mold and control of the red spider, in that it adheres very firmly to the leaf and is not easily washed off. It can also be used quite effectively if mixed with the ordinary sulfur, used in spraying.

SUPERNATANT LIQUOR

A SEPARATE SLUDGE DIGESTION OPERATING PROBLEM*

By Earl M. Kelly

Engineer, The Dorr Company, Inc.

An inspection of a large number of sewage treatment plants employing digestion indicates that the successful handling of the supernatant liquor from digesters is an operating problem of major importance.

Supernatant Liquor

Characteristics.—A knowledge of the characteristics of the supernatant liquor from separate digesters is essential to a better understanding of the correct method of handling such liquor. Unfortunately, with few exceptions, western sewage treatment plants do not regularly include analyses of the digester overflow as part of the testing routine. Consequently, it will be necessary to refer to eastern and middle western installations for this information.

A most comprehensive survey of supernatant liquor was presented by A. J. Fischer in 1934, before the Annual Meeting of the New York State Sewage Works Association. This discussion gave analyses of overflow liquors from twenty-three sewage plants located in various parts of the country.

From fifteen plants digesting raw sludge alone, the total solids averaged 2,823 p.p.m., and the suspended solids 1,516 p.p.m.

From three plants digesting raw and trickling filter sludge, the supernatant contained an average of 8,766 p.p.m. total solids and 5,800 p.p.m. suspended solids. Analyses from five plants digesting raw and activated sludge disclosed an average of 9,438 p.p.m. total solids and 4,530 p.p.m. suspended solids. Fischer further reported that the 5-day B.O.D. ranged from 150 to 30,000 p.p.m., the average being about 250 p.p.m. when the total solids approximated 3,000 p.p.m.

From the above data it is evident that the character of digester supernatant is subject to wide variation. Needless to say, the type of digestion and method of operation capable of producing a supernatant of best possible quality definitely is to be desired.

Factors Affecting Quality.—A few of the many factors affecting the quality of the digester liquor will be briefly mentioned.

The type of sludge digested has a direct bearing. In general, supernatant from tanks digesting raw sludge only will contain less solids than those digesting mixed sludges. Similarly, digesters handling only domestic solids will discharge a supernatant of superior quality to that discharged if the sludge contains a large percentage of packinghouse or cannery wastes.

Observations indicate that a raw sludge containing a greater per-

* Presented at the Ninth Annual Convention of the California Sewage Works Association, San Jose, Sept. 14, 1937.

centage of volatile constituents will discharge a supernatant of higher solids content than if the percentage of volatile solids were lower. If this contention is correct, the supernatant from many California digesters should be relatively high in solids.

The period of digestion is likewise important. With short digestion periods, internal disturbances due to gasification and other causes are greater per unit of tank area, scum forming tendencies are more prevalent, and the possibilities of digestion process upsets are greater. Consequently, the digester overflow contains more solids.

The design of the digester has an important bearing. Not only should it be capable of digesting the sewage solids but it should also contain provisions for a separation of solids from the liquids. Obviously, therefore, sedimentation plays an important part, and the units should allow sufficient settling area for such separation.

Maintaining the digester at the optimum digestion temperature for most rapid digestion to insure maximum capacity, and at the same time keeping the temperature uniform to eliminate convection currents, is important. Even in California, insulation of digesters to prevent night and day and seasonal temperature variations is worthy of consideration. Digestion at temperatures from 90 to 95° F. is considered optimum. At higher temperatures, up to the thermophilic range, a supernatant of higher solids with a high percentage of non-settling colloidal solids is produced.

The rate of sludge pumping is of unusual importance. Pumping at a high rate a short time each day will produce a supernatant much more difficult to handle than when an equivalent amount is pumped at a lower rate and more uniformly throughout the day. Pumping as thick a sludge as possible will minimize disturbances to the digester sedimentation processes, decrease the quantity of supernatant, and is to be greatly desired.

Methods of Handling Liquor.—Many methods of handling the supernatant liquor have been considered, including chemical treatment, oxidation, complete elimination by discharging digested sludge at the rate of raw sludge input, sand bed disposal and return to the sewage plant influent.

For numerous reasons which will not be mentioned here, practically all primary, and many complete treatment plants using separate sludge digestion, use the last named method of handling.

Where the supernatant is returned to the influent, it is of great importance to return this liquor as uniformly as possible and at a low solids content to prevent plant upset.

For example, if a primary plant, treating 1.0 m.g.d. averaging 290 p.p.m., effects a removal of 66 per cent, there are 1,594 lbs. pumped to the digesters daily. At 95 per cent moisture this amounts to 3,734 gallons of sludge daily, resulting in a supernatant return of approximatly 3,640 gallons. If this supernatant contains 2,823 p.p.m., 5.3 per cent of the solids entering the digester is being returned to the influent. Should the supernatant be of poorer quality and contain 13,000 p.pm.,

the percentage of solids returned as compared to those entering the digester would be 24.5 per cent.

Pumping sludge at 90 per cent moisture, which is possible, produces approximately one-half the supernatant resulting from 95 per cent moisture sludge and one-quarter that from 97.5 per cent sludge.

If the sludge pumping is at a high rate for a short period daily, and the sludge has a high moisture content, the amount of suspended solids returned to the influent may equal or exceed those contained in the incoming raw sewage.

Under these conditions, the overflow liquor contains an unusually large amount of highly septic solids of which a considerable proportion are non-settling in the sedimentation period provided by the clarifier.

Consequently, returning this liquor may render the clarifier either partially or completely septic, resulting in heavy scum formation on the clarifier surface with attendant odor nuisance, and a general upsetting of plant results. The efficiency of treatment is impaired and a considerable portion of the solids contained in the supernatant liquor may pass out with the clarifier effluent.

Although proper sludge pumping will undoubtedly improve plant operation, often the design of the digester makes impossible the production of a satisfactory supernatant.

The Multdigestion System, a relatively new process for the digestion of sewage solids, now in operation at over 30 representative plants, offers distinct advantages over the older single-stage and series digesters, from the standpoint of conditioning the supernatant liquor for return to the plant influent.

Essentially, the Multdigestion System, which may be inspected at the Santa Clara, San Mateo, and other western plants, consists of digesting sewage sludge in two steps. Raw sludge is pumped to the tank used in the first step, and an equal volume of digested sludge is displaced from the bottom of this unit through an inverted siphon to the tank or tanks used in the second step.

In the first, or primary, digester special agitators of the Turbo-Mixer type are provided to maintain a uniform mixture throughout the tank and to prevent a segregation of solids. Uniform temperature control is accomplished in this tank by means of special removable vertical heat exchangers located adjacent to the mixers. The primary digestion period is determined to permit a maximum decomposition of volatile solids in this tank.

Under normal operating conditions, digestion proceeds exceptionally fast in the primary unit. As raw sludge enters the tank, it is immediately seeded with digested sludge and heated to the temperature of the rest of the tank through the homogeneous mixing ability of the special agitators. This treatment produces an immediate acceleration of the normal digestion processes, resulting in rapid, uniform gastification and liquefaction. Scum formation is minimized. Usually over 90 per cent of the total gas produced in digestion is generated in the primary unit.

The secondary digester is a plain, unheated tank provided with a special steel gas holder cover. The size of tank is sufficient to provide the proper storage period for sludge thickening, sedimentation of supernatant, and sludge disposal requirements of the plant.

As the contents of the primary digester are thoroughly mixed, and no stratification is permitted, the digested sludge displaced to the secondary digester will be thick and uniform in character. In the secondary tank, due to the fact that a substantial quiescent zone is provided, the sludge rapidly concentrates to 90 to 95 per cent moisture, depending upon the storage period and character of the sludge. The supernatant liquor obtained is much clearer than would be obtained from a single-stage digestion unit because of the greatly reduced rate of gas production per unit of secondary tank surface area, the greater part of the gas having been obtained in the primary tank. The clarity of the supernatant liquor is a direct function of the degree of digestion. A much clearer liquor is obtained from a tank where only well-digested sludge is concentrated, as in the case of the Multdigestion System, than would be possible if part of the sludge handled was undigested.

The gas holder cover of the secondary digester stores the gas produced by both digesters. The capacity of the holder may be varied to suit requirements and percentage of total gas produced which is to be utilized.

The Ensley plant at Birmingham, Alabama, contains two type K Dorr digesters operated as single-stage units in parallel. The two digesters at the Birmingham Shades Valley Plant are operated in series, with a Turbo-Mixer mechanism and heating coils in the primary and no mechanism in the secondary.

The supernatant liquor from the Ensley single-stage digesters contained an average suspended solids content of 1,500 p.p.m. and a B.O.D. of 340 p.p.m. Analyses of the supernatant liquor from the two-stage digestion system at the Shades Valley plant showed an average of 200 p.p.m. suspended solids and 60 p.p.m. B.O.D.

Experiences at the Newark, New York, sewage treatment plant, as reported by Thomas J. Smith, illustrate even more conclusively the advantages of this improved digestion system.

This plant provides activated sludge treatment and is designed for a daily flow of 1.5 m.g. The excess activated sludge is returned to the influent for sedimentation in the primary clarifier. The mixed sludges are pumped to the digestion system.

The digestion system consists of two 30 ft. diameter tanks arranged for parallel or series operation. The primary digester, an old converted Imhoff tank, is equipped with a Turbo Mixer, and the secondary has a Dorr digester mechanism.

For a period of 247 days, the digesters were operated in series with intensive mixing in the primary. During this interval the gas production averaged 6,100 cu. ft. per 24 hours. The supernatant contained 2,700 p.p.m. and could be returned to the plant influent without causing difficulty.

At the expiration of this test period, the Turbo-Mixer was removed and the digesters were operated in parallel as originally planned. This method of operation was studied for 152 days. The average gas production dropped to 4,060 cu. ft. per 24 hr., or a decrease of 33.4 per cent. The total solids in the supernatant liquor were increased to over 20,000 p.p.m., which, when returned to the plant, caused severe septic action in the primary clarifier and aerators.

The very poor results from single-stage operation necessitated a return to two-stage digestion with the Turbo-Mixer in the primary. Data for a period of 211 days following the resumption of stage digestion showed the average daily gas production was increased to 6,230 cu. ft., and the plant operation became as efficient as before.

The above illustrations, together with other operating data not listed here, show conclusively that the Multdigestion System offers a valuable process for the proper conditioning of digester supernatant liquor for satisfactory disposal.

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RAGS AND GREASE AT THE CITY OF LOS ANGELES' TERMINAL ISLAND TREATMENT PLANT *

By H. G. Smith

Engineer In Charge of Plant Design and Operation

While the usual number of "bugs" encountered in starting up a new treatment plant made their appearance in due time at Terminal Island, undoubtedly the most trying on the mental and physical condition of all concerned have been rags and grease.

All sewage received at this plant now arrives by way of two force mains and makes its first appearance when entering the siphon feed clarifier. These force mains are fed by four separate pumping plants, in turn receiving the sewage from the San Pedro, Wilmington, and Terminal Island areas, a total of some 3.25 m.g.d., averaging over 400 parts per million suspended solids.

Each of these pumping plants is equipped with bar screens having 2½ or 3 inch clear openings and as available money for construction was somewhat limited and the installation of a bar screen under such conditions relatively costly, it was decided to eliminate this usual ad-

* Presented at the Ninth Annual Convention of the California Sewage Works Association, San Jose, Sept. 14, 1937.

junct and install a type of sludge pump capable of handling and grinding such rags as might escape the bars at the pumping plants.

Rags, Trash and Beer Cans.—From the standpoint of expecting that the rags escaping the plants would be only the smaller and less troublesome ones, this proved to be a mistake. Aside from suits of underwear, legs of overalls, socks and ladies' wearing apparel which managed now and then to dodge the bars and pass through the pumps, the smaller strips wound themselves into balls and after collecting hair and other debris finally presented themselves at the suction end of the sludge pumps.

These pumps with 4-inch suctions and rated capacities of 50 g.p.m. and powered by 2½ H.P. vari-speed motors, according to the manufacturers, were ready to take anything that came their way in the textile line, first grinding it up before passing it on to the impellers. While this type and size of pump had apparently functioned perfectly on underwear of genteel inland towns, they had never been up against such he-man stuff as the Port of San Pedro discards. At any rate they baulked in spite of all the efforts and gentle words of the operators, so the manufacturer's agent was called in and given a working demonstration. This resulted in a visit by the manufacturer's chief engineer, who, after quite an extended study of the particular conditions, went back to his factory and arranged the fabrication of an entire new unit. This installation has proven very satisfactory, and while it may grunt now and then over some extended wardrobe, it soon chews it up and carries on. The pump company is now about to install a second and similar unit which in connection with a plunger pump used for recirculation, standby and plugged lines, a high pressure water type pump for wash water and also plugged lines, together with a sewage trash pump handling the sump and a Jaeger portable for miscellaneous use, make up a very serviceable combination.

However, as all of these pumps decline beer cans and two by fours, which are becoming all too frequent, a trash rack is being constructed in the final contract for the completion of the treatment plant, which it is believed will be beneficial to the operation of the pumps as well as the mental condition of the operators.

Grease and Fish Oil.—While the San Pedro area holds the palm for rags, the Wilmington area contributes by far the larger portion of the grease and oil. The bulk of this grease originates at several fish canneries, and at times has covered the surface of the 80-foot clarifier with from two to four inches of glutinous matter for several hours at a time in spite of all efforts of the different types of skimmers so far installed.

Although it is the policy of the Bureau to handle all trade wastes entering the sewer up to a reasonable amount, efforts have been made to have these industries treat and recover this waste at their plants. By installing certain equipment, one of these concerns has cut the suspended solids from 39,000 to 2,830 p.p.m., and the oil from 7,940 to 1,710 p.p.m.

An ordinance was also adopted by the City Council restricting oil

or grease entering the sewer to 600 p.p.m. and suspended solids to 1,000 p.p.m., but it has been difficult to enforce. When considerable pressure has been brought to bear by the City the industries have turned the waste into the harbor, whereupon after a time certain shipping interests have "turned the heat on," and threatened damage suits, with the results that the wastes go back into the sewer again.

In the original clarifier installation, the ordinary bar type of skimmer was used. As this proved inadequate the Dorr Company furnished a new type of skimming equipment consisting of a floating cylinder approximately 8 inches in diameter and 9 feet long. Attached to the rake arms this moves in a radial position around the outer surface of the tank collecting the grease and pushing it on ahead. Beneath the steel bridge of the clarifier a metal trough is installed, the lip of one side being just at the surface of the liquid. As the floating cylinder, pushing the mass of grease ahead, approaches within a few feet of the trough, it trips a lever and by means of interconnecting mechanism causes the lip, which is hinged to the trough, to dip below the surface a sufficient depth to allow the collected grease to flow into the trough, from which it is discharged by gravity to the outlet pipe. As the floating cylinder actually reaches the trough the mechanism returns the lip to its original position while the cylinder ducks beneath the trough to bob up on the opposite side and continue again around the tank.

This device will operate at a plant receiving a normal amount of grease with very little attention, and is undoubtedly an improvement on the old bar skimmer. However with the great quantities of grease received at Terminal Island, particularly during the sardine season, this equipment becomes "snowed under" and a new paddle type of skimmer devised by our chief operator, Mr. Fiscus, is being installed.

The floating cylinder will still be used for collecting the grease but in place of the trough will push the floating matter against a fixed baffle where a series of paddles suspended from endless chains running on sprockets and operating adjacent and parallel to this baffle, will draw the grease to and up a ramp ending at the outlet pipe.

Until quite recently this grease was discharged onto sand beds, permitted to dry and finally burned in a temporary furnace using a portion of the surplus gas from the digester, amounting to some 80,000 to 90,000 cu. ft. per day, to assist in the incineration. This proved very cumbersome and laborious and the method has been superseded by flowing all grease to the sump and pumping it into the digester. Thus far there does not seem to be any serious resentment on the part of that unit.

The final contract for the sludge beds, incinerator, bar screens, drives, walks and parking of the grounds, is now under way, and it is believed that the vexatious problems above enumerated have been or are about to be solved.

Editorial

SLUDGE AS FERTILIZER

The report of Mr. Pearse's committee on the utilization of sewage sludge as fertilizer occupies a considerable part of this issue. The report is the most complete that has ever been assembled on this topic and should be of great value to plant operators in this country and abroad. Mr. Pearse wrote on a subject that has interested him for years, and he covered the topic with his usual thoroughness, aided by the contributions of the members of the committee.

At first reading, the number of tables and the large amount of data therein may be somewhat confusing to the average reader who wishes to draw his own conclusions as to the significance of the report as applied to his problem. However, the committee conclusions and recommendations are quite brief and clear; they comprise the gist of the report and give a true picture of the present status of the use of sludge as fertilizer.

Although the total tonnage of digested sludge available is enormous, the actual amount of such sludge that is dried by heat and sold is relatively negligible (Table XXII). The data are not likely to raise any enthusiasm for this procedure for general use. A valuable study of the economics of this procedure is presented by Kraus (Ref. 60a) who is unable to see any prospect of profit at Peoria by heat-drying a rather rich digested sludge.

Use of digested air dried sludge, however, is increasing and local use of such sludge is certainly warranted. The most valuable reference in the bibliography, in the writer's opinion, is the paper by Dr. De Turk (Ref. 31), because he has given the real "low-down" on the quality and value of all types of sludge, and his conclusions leave one with the conviction that the nitrogen in digested sludge is of very low availability, whereas activated sludge is shown to be not only twice as rich in nitrogen as digested sludge, but the nitrogen is also twice as available. One might summarize his conclusions in a sentence: Digested sludge is fit only for local consumption, with a nominal charge; undigested activated sludge is of marked value as a fertilizer and warrants mechanical drying and sale in direct competition with established organic fertilizers.

The committee conclusions have followed Dr. De Turk's lead and state "It would appear that the heat-drying of digested sludge depends for its success on conditions such as the soil and the crops and on the effort and skill of the sewage works manager in exploiting the product, as well as on the analysis." The words "as well as" might be changed to "rather than" to conform with Dr. De Turk's (and the writer's) views.

Activated sludge has hardly had the recognition it deserves as a true fertilizer, although the early pot-culture experiments of Bartow and Hatfield (Ref. 64) and later of Noer (Ref. 63) are outstanding in proving its value. Fraps (Ref. 18), in his study of sludges of various types from Texas plants, shows conclusively the value of activated sludge as contrasted with digested sludge, and in competition with commercial fertilizers. It seems deplorable that digestion is practiced so widely in the disposal of activated sludge, first, because digestion of activated sludge is relatively expensive, as compared with primary sludge, on account of the high moisture content of digesting activated sludge, and second, because of the loss of nitrogen and depreciation of the availability of the remaining nitrogen, thus ruining the sludge as a commercial fertilizer. It has been thought that only the largest cities could consider artificial drying of sludge, as at Milwaukee, but improvements in mechanical equipment for drying sludge may make this procedure available for smaller places. From the standpoint of conservation of resources, it is an economic loss to digest activated sludge.

The references in the Committee report that have been discussed here should be looked up by all readers, and in addition the papers by Tanner (86) and Ruchhoft (87) should be read, with reference to the hygienic aspects of sludge disposal. Some of these papers have been published in THIS JOURNAL (Refs. 31, 60a, 86 and 87). Some of the most valuable contributions to this subject have been made by experts in other professions than sewage treatment, notably agronomists (Fraps, De Turk, Noer) and chemists and bacteriologists (Tanner, Bartow, Paden, Haskins). Possibly a better perspective of the situation as a whole may be obtained by specialists in allied fields, rather than by those whose specialty is sewage treatment.

F. W. M.

Proceedings of Local Associations

CALIFORNIA SEWAGE WORKS ASSOCIATION

Tenth Annual Convention

San Jose, California, Sept. 13–14, 1937

The tenth annual convention of the California Sewage Works Association was held in San Jose, California, September 13–14, 1937, jointly with the League of California Municipalities.

San Jose is situated at the most southerly end of the San Francisco Bay, in the Santa Clara Valley, which valley is famous for its prunes and fruits.

The Association's inspection "caravan" on the first day of the convention was again limited to one-half day, which allowed more time for sessions but still allowed ample time to inspect the large Pratt-Low cannery at Santa Clara, where pears, peaches and tomatoes were being packed, and two small treatment plants.

After an hour observing the various canning processes, the caravan consisting of around 150 members and guests proceeded to the Santa Clara sewage treatment plant, which receives the wastes from the above cannery, and consists of a clarifier with separate sludge digestion. The effluent from the plant is used for the irrigation of such crops as sugar beets and seeds.

Continuing, the caravan arrived at the Los Gatos treatment plant at 11:00 a.m. This plant is one of the oldest Imhoff-trickling filter plants in the State and the only plant where the tanks and filters are covered for odor control. The gas is burned.

Luncheon was had at the De Anza Hotel with eighty in attendance, mostly members.

The afternoon of the first day was given over to a Symposium on operating problems, which brought out many important operating difficulties and the suggestion to the operator, engineer and equipment man that many of the difficulties can be eliminated by mutual cooperation. Seventy-five attended this session.

Hollis R. Thompson, City Manager of Berkeley and Past President of the League of California Municipalities, spoke on the subject "Civic Affairs" at the dinner meeting Monday evening. His theme was that the inhabitants of cities were demanding more service at reduced cost, and that each official's duty was to render the best service possible with the funds available, to acquaint himself with all the functions of the city, and to advise the citizen of the services he receives. Cooperation of various bureaus and political subdivisions, careful planning and foresight, it was said, will determine the future prosperity, health and happiness of a community.

The Engineers and Planners Section of the League were invited to attend the dinner meeting. There were two hundred forty members and guests present.

The morning session of the second day was opened with Committee Reports. The Committee on Certification and Schools reported that fifty-two sewage treatment plant operators had applied for certification and had been rated as Grade I, II, or III. The short school for plant operators held at the University of Southern California, June 14 to 18, inclusive, was very successful and plans are now being made for a short school in the northern part of the State during the summer of 1938.

The two papers of the morning session were of an informational character for the plant operators. Mr. George A. Weber explained "Electricity for the Sewage Works Operator" in a chalk talk with many sketches and diagrams illustrative of how motors, controls and switches function and closed with a warning of the dangers of carelessness when dealing with electrical currents. Mr. Ray L. Derby in his paper "Bacteriology in Relation to Sewage Disposal" omitted nothing in the field of bacteriology that applies to sewage treatment.

Three papers were presented at the afternoon session, which was conducted jointly with the Engineers' Section of the League. There were one-hundred twenty-five in attendance. Professor C. G. Hyde's paper on "Uses of Activated Sludge Plant Effluent in Golden Gate Park" was illustrated with lantern slides showing the many lakes, waterfalls, rivulets and ferny dells created by the use of the effluent of the 500,000 gallon activated sludge plant located in the park. Mr. George A. Parkes discussed the "Supervision of Treatment Plant Operation by the Engineer of Design" indicating procedures that may result in establishing a fundamental basis of operation. The final paper of the session by Jean L. Vincenz on "Charges for Sewer Connections from Outside Areas to the City Sewer Systems," discussed by J. F. Byxbee, Lloyd Aldrich, and W. L. Popp, was the first open discussion of this important problem of California cities.

The following officers were unanimously elected: *President,* R. F. Goudey, Sanitary Engineer, Dept. of Water and Power, Los Angeles; *First Vice-President,* Alexander Bell, Western Sales Manager, Wallace and Tiernan Company, San Francisco; *Second Vice-President,* H. G. Smith, Engineer of Sewer Design, Los Angeles; *Secretary-Treasurer,* R. R. Ribal, Oakland; *Director* (5 years), B. D. Phelps, Asst. City Engr., San Diego; *Board of Control,* Austin Burt, City Service Manager, Ontario.

R. R. Ribal, *Secretary-Treasurer*

NEW YORK STATE SEWAGE WORKS ASSOCIATION

Fall Meeting

Elmira, N. Y., Oct. 15–16, 1937

The fall meeting of the New York State Sewage Works Association was held on October 15 and 16, 1937, at the Mark Twain Hotel, Elmira. There were registered 170 members and guests, including 23 ladies.

At the Friday morning business meeting reference was made to the proposed laboratory schools for sewage works operators to be held at Cornell University and New York University. Announcement was also made regarding the meetings for 1938. The annual meeting will be held in New York City in January, the spring meeting in Buffalo in June, and the fall meeting will be a joint meeting with the New England Sewage Works Association at Hartford, Conn., about the 1st of October, at which manufacturers' exhibits will be displayed.

At the technical session Friday morning Richard E. Gorman, District Sanitary Engineer, New York State Department of Health, presented a paper on "Sewerage and Sewage Treatment in the Elmira Area," and Mr. Anselmo F. Dappert, Principal Sanitary Engineer, New York State Department of Health, presented a paper on "Qualifications Prescribed for Sewage Treatment Plant Operators," setting forth the regulations recently promulgated by the Public Health Council, which took effect October 1, 1937. A paper on "Chemical Treatment of Sewage," prepared by Philip B. Streander, Consulting Engineer, New York City, was read by the chairman of the Program Committee in the absence of the author.

President Charles C. Agar presided at the luncheon and introduced the guest speaker, Hon. J. Maxwell Beers, Mayor of the City of Elmira.

The afternoon session was devoted to papers prepared by operators, and the papers and discussion that followed proved most instructive. The following papers were presented:

"Maintenance of Pumping Stations and Force Mains," John V. Lewis, Director of Maintenance and Operation, Department of Public Works, Rochester.

"The Mineola Sewage Treatment Plant," Frank H. Hall, Chief Operator, Sewage Treatment Plant, Mineola.

"Operation of Imhoff Tanks," Channel Samson, Superintendent of Sewers, Town of Tonawanda, Kenmore.

"Sludge Digestion without Heat," L. R. Smith, Superintendent of Water and Sewers, Canton.

"Sludge Digestion with Heat," Herbert O. Johnson, Superintendent of Sewers, Belgrave Sewer District, Great Neck.

"Operation of Covered Sludge Beds," Elvey A. Marshall, Chief Operator, Sewage Treatment Plant, Geneva.

"Operation of Open Sludge Beds," William A. Ryan, Sanitary Chemist, Rochester.

Friday noon the ladies had lunch at the Mark Twain Hotel and then visited the plant of the Thatcher Manufacturing Company, one of the largest manufacturers of milk bottles in the country.

Friday evening following the usual informal banquet, the group were entertained with vocal solos by Mrs. Joseph Keefe, and a program of variety dances. Following the entertainment dancing was enjoyed until midnight.

Saturday morning 80 men arose in time for the Sunrise Breakfast, and discussed their problems in a Question Box conducted by Morris M. Cohn. Announcement was made of the results of the balloting in the gadget competition. The First Award went to William W. Watkins, Superintendent of Water and Sewage Treatment at Oneonta, for "Homemade Sludge Grinder and Loader"; the Second Award to William M. Foley, Chief Engineer, Schenectady County Home, "Vacuum Scum Breaker for Use in Gas Vents of Imhoff Tanks"; the Third Award to C. George, Superintendent of Sewers, Rockville Centre, "Portable Equipment for Handling Dried Sludge from a Sludge Drying Bed." Along with the gadgets were displayed some 25 emblem designs submitted in the emblem contest. Announcement regarding the emblem will be made later.

Gerald J. McInerney, Chief Operator, Sewage Treatment Plant, Elmira, presented an excellent descriptive paper on the Elmira sewage treatment works, and each member was furnished with a printed copy of the paper and a flow diagram of the sewage treatment plant.

Under police escort an automobile caravan of some 25 cars inspected the new Elmira sewage treatment works. This compact plant provides for treatment by chemical precipitation of the sewage, with chlorination of the final effluent, and consists of pumping station, mechanically cleaned bar screens, rapid mix and flocculation channels, settling tanks with upward flow magnetite filters and chlorine reaction tank. The raw sludge, after being chemically conditioned, is dewatered on vacuum filters and the sludge cake burned in a multiple hearth incinerator. Following this inspection a number of the group visited the Elmira plant of the Shelt Company, manufacturers of corrugated pipe, where they viewed the complete processing of the pipe, including coating and paving of asbestos coated pipe.

The next meeting of the Association will be the tenth annual meeting in New York City, January 20, 21 and 22, 1938.

A. S. BEDELL, *Secretary-Treasurer*

CENTRAL STATES SEWAGE WORKS ASSOCIATION

Tenth Annual Meeting

St. Paul, Minn., Oct. 21, 1937

The tenth annual meeting of the Central States Sewage Works Association was called to order by President H. E. Babbitt at the Hotel Lowry, St. Paul, Minnesota, on October 21, 1937. Total registration for the meeting was 149 members and guests.

BUSINESS MEETING, OCTOBER 21—PRESIDENT H. E. BABBITT, PRESIDING

The report of the Secretary-Treasurer was read and accepted subject to the report of the auditing committee.

The following committees were appointed to function during the meeting:

Nominating Committee
W. W. DeBerard, Illinois.
E. J. Beatty, Wisconsin.
A. J. Duvall, Minnesota.
C. B. Carpenter, Indiana.

Resolutions Committee
W. B. Walraven, Illinois.
C. C. Wilbur, Minnesota.
G. M. Hall, Wisconsin.
Don Bloodgood, Indiana.

Auditing Committee
K. L. Mick, Minnesota.
B. A. Poole, Indiana.
H. O. Lord, Wisconsin.

The constitution committee submitted an amended constitution which was read and discussed at this session. Several changes in the proposed draft were adopted, these changes to be incorporated by the Secretary before mailing to the membership for final adoption by letter ballot.

At the conclusion of this session, the Association was welcomed to St. Paul by Mayor Mark Gehan, who presented President Babbitt with the key to the city.

TECHNICAL PROGRAM

The program given below lists the papers presented on the technical program. This program was most profitable and interesting and was well received by all in attendance.

It will be noted that luncheon addresses by W. D. Hurst and F. M. Veatch relative to the Winnipeg, Manitoba, and Denver, Colorado, sewage treatment plants, respectively, augmented the regular technical program.

THURSDAY, OCTOBER 21

MORNING SESSION

12:00 Luncheon—Grand Ballroom.
Speaker: "Sewage Treatment in Canada with Special Reference to Winnipeg, Manitoba, Plant"—W. D. Hurst, Secretary, Board of Engineers, Greater Winnipeg Sanitary District.

AFTERNOON SESSION

(Spanish Room)

Vice-President F. M. DAWSON, *Presiding*

1:00 "Struggles with Packinghouse Wastes at Sioux Falls"—Leland Bradney, Chemist and R. E. Bragstad, City Engineer, Sioux Falls, South Dakota.

"Cedar Rapids' Agreement with Packers"—H. R. Green, Consulting Engineer, Cedar Rapids, Iowa.

"Sewage Treatment and Industrial Wastes in Fox River Valley"—Samuel A. Greeley, Consulting Engineer, Chicago, Illinois.

"The Viscosity or Pseudo-Plastic Properties of Sewage Sludges"—W. D. Hatfield, Superintendent, Decatur Sanitary District, Decatur, Illinois.

FRIDAY, OCTOBER 22

MORNING SESSION

B. A. POOLE, *Presiding*

9:00 "Laboratories for Sewage Treatment Works"—Emanuel Hurwitz, Chemist, Sanitary District of Chicago.

"Oxygen Demand Studies at Indianapolis"—Donald E. Bloodgood, Superintendent, Sewage Treatment Works, Indinapolis, Indiana.

"High Lights in Tunnel Construction"—C. C. Wilbur, Engineer, Minneapolis-St. Paul Sanitary District, St. Paul, Minnesota.

"Layout and Plan of Operation of the Minneapolis-St. Paul Sewage Treatment Works"—George J. Schroepfer, Sanitary Engineer, Minneapolis-St. Paul Sanitary District, St. Paul, Minnesota.

12:00 Business Luncheon—Main Dining Room.
Speaker: "Sewage Treatment in the Rocky Mountain Region, with Special Reference to Denver, Colorado, Plant"—F. M. Veatch, Consulting Engineer, Kansas City, Missouri.

AFTERNOON

3:00 Inspection of Minneapolis-St. Paul Sanitary District Sewage Treatment Works. (Transportation will be provided with return to Hotel Lowry about 5:00 P.M.)

BUSINESS MEETING, OCTOBER 22—PRESIDENT H. E. BABBITT, PRESIDING

Report of the Awards Committee was presented by W. G. Kirchoffer. In accordance with the intent of the new constitution, it was recommended that no awards be made for the papers presented at Indianapolis in 1936. This recommendation was not accepted, however, and the matter was referred back to the committee for definite recommendations for awards.

Four gadgets were exhibited and prizes were authorized by ballot as follows:

Gadget	*Entered by*	*Award*
Sludge sampler	Geo. Martin, Green Bay, Wis.	$5.00
B.O.Dette	C. C. Larson, Springfield, Ill.	3.00
Glass cutter	E. P. Baillie, Madison, Wis.	2.00

The auditing committee reported favorably on the books and records of the Secretary-Treasurer and his reports were accepted to be placed on file.

Resolutions were presented and referred to the Secretary regarding the deaths in 1937 of Gus. H. Radebaugh and Chas. Brossman, the serious illness of Harry E. Wilson and the excellent arrangements and hospitality of those who collaborated in making the St. Paul meeting such an outstanding success.

The following officers to serve in 1937–38 were elected by unanimous ballot upon recommendation of the nominating committee:

President—F. M. Dawson, Iowa City, Iowa.
First Vice-President—G. J. Schroepfer, St. Paul, Minn.
Second Vice-President—B. A. Poole, Indianapolis, Ind.
Third Vice-President—C. C. Larson, Springfield, Ill.
Secretary-Treasurer—W. H. Wisely, Springfield, Ill.
Representative to Federation
Board of Control—W. W. DeBerard, Chicago, Ill.
—J. L. Ferebee, Milwaukee, Wis.

Letters of invitation to the Association to hold the 1938 meeting at Neenah-Menasha or Milwaukee, Wisconsin, were read. Selection of the next meeting place will be made later by the executive committee and it was recommended that a location be chosen somewhere in the Fox River valley of Wisconsin.

W. H. Wisely, *Secretary-Treasurer*

THE CANADIAN INSTITUTE ON SEWAGE AND SANITATION

Fourth Annual Convention

London, Ontario, Oct. 21–22, 1937

The fourth annual convention of the Canadian Institute on Sewage and Sanitation held in London, October 21st and 22nd, 1937, was a most successful gathering. This was the first time the meeting has been held outside of Toronto, but the registration of 111 gave no doubt as to the wisdom of the choice of location.

President Grant R. Jack was in the chair when the program of papers started on Thursday afternoon with a presentation on "Developments in Sewage Sludge Incineration," by Mark B. Owen, of the Nichols Engineering and Research Corporation, New York. This paper contained a description of some of the works in operation, and discussed the field of application for this process.

The second paper dealt with the "Use and Misuse of Terms in Sewerage and Sewage Disposal Practice." It was given by Wm. Storrie, Consulting Engineer, Toronto. Following this a resolution was passed referring to the Executive Committee the question of taking some action on the adoption of certain terms for use in this field.

A series of 3 papers was devoted to methods used in refuse collection. The procedures followed in three Ontario cities were described by the Engineers for those places namely, W. C. Miller, St. Thomas; W. L. McFaul, Hamilton; and W. H. Riehl, Stratford.

The final paper of the afternoon was presented by Stanley Shupe, City Engineer of Kitchener, on the subject of the "Effect of Trade Wastes on Sewers and Treatment Works."

The Business Meeting

The Friday morning session opened with the usual business meeting of the Institute. The Secretary presented a review of the year's activities. This contained two main features namely an increase in membership from 70 to 82; and the inauguration of the "Municipal Sanitation Data," a project through which all members of the Institute receive compilations of statistics and data on practices in Municipal Sanitation in Canada. This is distributed in loose leaf form, with a suitable cover being provided.

Election of Officers

The election of Officers for the ensuing year resulted as follows:

President, N. J. Howard, Toronto.
Vice-President, W. C. Miller, St. Thomas.
Trustees, W. H. Riehl, Stratford.
S. Shupe, Kitchener.

The other continuing members of the executive committee are Past President—Grant R. Jack, East York Township, and Secretary-Treasurer—A. E. Berry, Toronto.

The London Treatment Plants

City Engineer, W. M. Veitch, read a paper dealing with the three sewage disposal works in London. Two of these are activated sludge, and one a sprinkling filter. The remainder of the morning session was devoted to a panel discussion on various subjects in Municipal Sanitation including Street Cleaning, Sewer Design, etc.

The Annual luncheon of the Institute on Friday noon saw a splendid number in attendance. Addresses were given by the President-Elect —N. J. Howard, E. V. Buchanan, Chairman of the Canadian Section A. W. W. A., and by the guest speaker Professor J. A. Spenceley of Western University.

The Convention concluded in the afternoon with a visit to the London Sewage Treatment Plant and the local refuse incinerator.

The number of delegates in attendance from widely scattered municipalities and the interest maintained throughout in the papers and the discussions were sufficient evidence of a successful meeting. No decision has as yet been made by the executive on the choice of next year's convention centre, but invitations have been received from Toronto and Hamilton.

A. E. Berry, *Secretary-Treasurer*

Reviews and Abstracts

H. W. Streeter

SEWAGE DISPOSAL AT BARNSLEY

Annual Report of the Manager and Chemist, *Surveyor*, 92, 197 (August 13, 1937)

In the seventeenth annual report, Mr. H. D. Bell gives the results of a process for disposing of the surplus activated sludge from the biofiltration plant. The light particles in the sludge are coagulated by the addition of 75.8 pounds of a sharp-grained dust per 1,000 gallons of waste sludge of an average moisture content of 99.34 per cent. After settling, 75 per cent of the supernatant liquor is drained off and the settled sludge discharged onto drying beds. The inert coagulant dilutes the nitrogen content of the dried sludge and increases the weight of the final product, but, by substituting suitable phosphates as part of the coagulant, a smaller proportional weight per 1,000 gal. of sludge is required for coagulation and a much better balanced fertilizer is obtained. This fertilizer has a ready sale locally and each year since its trial the sales have increased.

Trouble has been experienced in disposing of the dried primary sludge as the local farmers didn't appreciate its value enough to haul it away. It was thought that if the sludge could be dried to 15 to 20 per cent moisture and ground to a fine powder, it might be more readily disposable, but up to the beginning of the year only a few loads were taken. During the year, however, a contract was made for 400 tons of sludge dried to 15 per cent moisture, ground and bagged, F.O.B. cars, at a price allowing a small profit after paying the costs of grinding, bags and haulage.

Storm water has continued to give trouble. The storm water overflow is between the primary settling tanks and the activated sludge plant. Hence in time of storm the grit chambers and preliminary tanks have too short a period to function properly, the activated sludge plant becomes overloaded, and purification ceases temporarily.

The low level works receive septic sewage in summer due to deposits in some sewers that have settled. This requires the use of chemical treatment to assist the activated sludge process. Alumino-ferric is used as a coagulant and bleaching powder to restrict septic action. Perforated iron plates have been substituted for the wooden blades on the end of the paddle arms in the aeration tank channels. Although the area of the solid portion of these plates is slightly less than that of the wooden blades, a greater disturbance and splashing action have been obtained and they produce waves of a more permanent character, resulting in increased aeration but without any appreciable increase in power consumption.

The report states that the high level works have suffered from mining subsidence, the inlets to the tanks, filter outlets and floors in both tanks and filters being affected. The effluent channel from the first battery of filters will no longer carry the flow to the humus tanks and an earth lagoon has had to be utilized for secondary settling. Rebuilding is being postponed until the settlement of the ground is complete.

The daily dry weather flow to the high level works is 914,591 gallons and to the low level works 455,957 gallons, equivalent respectively to 20.6 and 19.2 gallons per capita connected.

R. S. Smith

THE RATIONALIZATION OF SEWAGE DISPOSAL

By C. B. Townend

Surveyor, **92**, 99–101 (July 23, 1937). *Discussion*, **92**, 147

The purpose of the paper is to suggest that local governments are frequently too limited to handle adequately many of the problems of sewage disposal and that the control of this work should be reorganized on a rational and regional basis.

A tremendous amount of excellent work has been carried out by individual sewage purification authorities and various river boards, but modern knowledge and experience is not universally applied and the law relating to water pollution is not sufficiently enforced. The parochial practice of permitting haphazard multiplication of sewage works has contributed in large measure to this state of affairs. For instance, within a 15-mile radius of Manchester Town Hall, no less than 100 authorities are responsible for sewage disposal. Such a multitude of small authorities frequently results in the financial inability to build complete modern plants as betterments and extensions are needed, some authorities, indeed, tenaciously retaining obsolete plant built in the last century, patching it up from time to time and wasting money in piecemeal fashion on long overdue extensions.

The deficiencies of the present organization would be overcome by the formation of regional sewage purification boards, each responsible for the administrative control of a large self-contained drainage district based on the natural catchment boundaries. Such an organization would permit the development of the area for the best advantage of all concerned, and would eliminate redundant plant and duplication of facilities. By concentrating sewage purification in larger central plants, it would make more possible the employment of an adequate staff, would balance sewage flows and probably reduce many of the deleterious effects of individual trade wastes. Another advantage of administration by regional boards would be in the equalization of tax charges throughout the district. Instead of many of the small areas being excessively taxed and in constant financial difficulties, the benefits would be shared by large and small communities alike.

The paper closes with suggestions for legislative action to accomplish the desired results in England.

R. S. Smith

HALIFAX SEWAGE DISPOSAL WORKS

Anon

Surveyor, **92**, 159 (August 6, 1937)

Halifax has a population of 98,115 and a dry weather sewage flow of 5 m.g.d., about forty per cent of which is trade waste from breweries, gas plants, tanneries, wire works, etc.

The sewage entering the plant passes through mechanically cleaned grit chambers and bar screens with 1-inch openings, before entering the chemical precipitation tanks. Grit and screenings amount to 1,600 tons annually. Sulfuric acid is added to the sewage to reduce the pH to 3.0 for coagulation before it enters the precipitation tanks. This primary sludge from the precipitation tanks is treated with sulfuric acid to bring the pH to 3.6 and then filtered in mechanically operated plate filter presses of 2-ton cake capacity. The press cake, with a 55 per cent moisture content, is dried to 12–15 per cent moisture content on 8 ft. wide belts passing through a drying chamber with a temperature of 100 degrees C. The cake then goes to a solvent grease extraction plant where the grease is extracted with benzine and the residue ground and sold as fertilizer.

The effluent from the chemical precipitation tanks is treated on trickling filters equipped with rotary distributors. The filters are of varying depths from 6 to 8 feet, and from 68 to 135 feet in diameter. The filtering effluent is passed through humus or secondary settling tanks before being discharged to the river.

The plant also contains two "Simplex" activated sludge units, which act as "buffer" plants during peak flows when the capacity of the trickling filters is exceeded.

R. S. SMITH

REMEDYING SEWER INFILTRATION

By N. S. BOWES

Surveyor, 92, 215 (August 20, 1937)

A method of locating points of infiltration of ground water into sewers has been developed in the Egham area of the Thames River valley where frequently the ground water is within one or two feet of the surface. The flow at the upper manhole of a section of sewer is temporarily blocked off and each house connection on the section plugged at the intercepting chamber. Then a movable plug is pulled upstream through the section, stopping at frequent intervals. The appearance of a flow of water indicates when the stopper passes the point of leakage. The location is noted and repairs are made during the summer and autumn when the ground water is lowest.

The first stopper used consisted of a metal bar with a wooden plate backed by a rubber disk at each end and with steel cables attached by which the device could be moved forward or backward. Irregularities in sewer pipe, rough joints and other inequalities caused leakage past the rubber disks, resulting in erroneous conclusions. These troubles were the cause of abandonment of the device and the substitution of an inflated bag stopper in a strong canvas envelope with a shackle and steel cable on the upstream end. A strong rubber hose, one-half inch in diameter and two to three hundred feet long is attached to the downstream end of the bag and serves as a means of hauling the bag back as well as inflating it. It is necessary to deflate the bag in order to move it and to inflate it at the next stopping point.

It has been found that most of the leaks occur where house connections leave a shallow trench and enter the backfill of the street sewer trench which is much deeper.

R. S. SMITH

THE BALANCE OF OXYGEN IN AN ACTIVATED SLUDGE TANK

By N. A. BASIAKINA

Publication of States Academy for Municipal Sciences. U.S.S.R., 1936 (From summary in English).

To determine the rôle of oxygen in the oxygen balance in an aeration tank, account must be taken of other factors such as the concentration of sewage and the purified liquid, the quantity of air and character of its distribution, the rate of oxygen absorption, time, temperature, etc. As it was impossible to carry out quantitatively such an experiment in the large aeration tanks, the test was made under laboratory conditions, using an experimental aeration tank 1.9 m. (6.25 ft.) deep and having a surface area of 0.00407 m^2 (6.3 sq. in.). The incoming air was measured and the outcoming air analyzed, the amount of oxygen absorbed being reckoned from the change thus observed in the air flow and composition.

Sewage is saturated with nitrogen, which passes through unchanged if no dentrification occurs. The oxygen dissolves in proportion to the saturation deficit. When the oxygen absorbed by oxidation diminishes, the oxygen deficit is decreased and thus the amount of oxygen absorbed from the air blown in. If the amount of oxygen utilized remains constant during a certain period of time, the whole amount of oxygen utilized is equal to

$$M = 2.099\, n\, s \frac{Q}{v}$$

where M = mg. O_2 per liter utilized by the sewage with sludge.
n = amount of utilized oxygen.
s = weight of 1 cc. of O_2 (about 1.3 mg.).
Q = volume of air passed through the liquid (liters).
v = volume of sewage-sludge mixtures in the tank (liters).

Because of the limitations of the aerating device, it was necessary to blow 54–60 liters of air per hour per 7.5 liters of the sewage-sludge mixture. In this way 110–120 mg. of O_2 per liter were obtained—an amount found necessary at the start. The amount of O_2 necessary for forming NO_2 and NO_3 was easy to calculate. The difference between the quantity of O_2 utilized in the tank and the amount consumed by nitrification was the quantity necessary for the oxidation of the activated sludge and sewage organic matters.

To find out the end of the process, the amount of oxygen consumed by the activated sludge alone was determined, whereby the liquid it was being aerated with was wholly mineralized. The B.O.D. of this liquid was 4.7 mg. in 20 days. The consumption of oxygen by the strongly mineralized sludge was 14–35 mg. per hour for 1 liter of activated sludge (2 hours of settling, moisture 97.6 per cent). As about 14 per cent of activated sludge was in the aeration tank while working, the consumption of O_2 per liter of mixture due to the sludge should have been 5 mg. per hour, a very small amount compared to that utilized by the sewage under these conditions (100 mg. per hour).

It was more difficult to determine the B.O.D. of the semi-purified sewage, as nitrification occurred in the dilution test during incubation. The nitrate method was therefore applied, noting the amounts of NH_3, N_2O_3 and N_2O_5 in the completely mineralized sewage and measuring the changes in these constituents during incubation. It was thus possible to determine the consumption of oxygen during periods of 20 days or more. By this method it was found that in aeration not only the quantity of organic matters is changed, but that they are being divided into parts, the first to be oxidized having a greater rate of oxidation. As mineralization proceeds, there remain substances of lesser and lesser rates of oxidation. When this rate is equal to the rate of oxidation of the sludge alone, the process is considered as completed.

The total amount of O_2 necessary for oxidation of organic matters during this period was 477 mg./liter. The B.O.D. of the sewage was 530 mg./liter. This was diluted by the mineralized liquid in the ratio $\frac{6.5}{7.5}$; hence the B.O.D. of the primary mixture was $\frac{6.5}{7.5} \times 530 = 459$ mg./liter. Thus the real quantity of O_2 utilized for oxidation of the organic matters was $\frac{(477-459)100}{477}$ = plus 4 per cent more than the B.O.D. of the sewage undergoing purification. Another experiment showed this to be 2 per cent less.

The conclusion may be drawn: (1) that the B.O.D. of sewage as determined by the nitrate method for 20 days' incubation gives the real amount of the substances biologically oxidized, and (2) that the purification process in the aeration tank may be summed up as the quantitative reduction of the B.O.D. at the expense of the oxygen absorbed. If we do not want to reach this highest point of purification in a normally working aeration tank, but wish to get the steady purification effect (*i.e.*, to return the activated sludge to its primary state), we have to oxidize the same quantity of organic substances as the difference between the B.O.D. of the sewage and that of the purified liquid.

If we supply the air in proportion to the intensity of oxidation, the amount of oxygen utilized for the oxidation will be

$$A = \frac{L_1 - L_t}{2.099\, s\, n}$$

where A = cu. meters of air per cu. meter of sewage.
L_1 = B.O.D. of the sewage.
L_t = B.O.D. of the purified liquid.
n = per cent of oxygen consumed.
s = specific gravity of the oxygen.

At the same time the amount of consumed oxygen is proportional to the depth of sewage in the aeration tank and to the oxygen deficit.

To what extent can this process be controlled? Is it possible to limit the quantity of air necessary for the nitrification at the end of the process without reducing the organic oxidation as we see it at the start of the process?

While examining separately the processes going on in the sewage and in the activated sludge, we see the phenomena mentioned before, namely, that at the beginning the reduction of the B.O.D. of the sewage is higher than that of the organic matters in the aeration tanks; that is, a part of the sewage material is being absorbed by the activated sludge. Later, while the B.O.D. undergoes but slight changes, an intensive process of oxidation still goes on. This process is the oxidation of the absorbed substances; that is, the regeneration of the sludge. So it is obvious that the steady result of an aeration tank work can be obtained only when all of the substances brought in by the sewage have been oxidized and the activated sludge restored to its primary state. Otherwise the sludge becomes polluted, a great amount of oxygen is required to oxidize this polluting material, and the sewage is still insufficiently purified. At the same time it has been shown that the rate of organic matters oxidation diminishes as the process of purification is going on.

The conclusion to be drawn is that the intensity of the sewage aeration must vary while the sewage is passing the tank. From a study of the absorption curve and the data showing the distribution of organic matters in the liquid during the process, the essential point emphasized is that in the aeration of organic matter of any concentration the B.O.D. of the sewage corresponds to a certain B.O.D. of the sludge, though evidently the distribution of the substance between the two phases does not give us the opportunity to examine the activated sludge and the purified liquid separately.

The rate of a biochemical process, specific for the organic matter oxidation in an aeration tank (when the air supply is sufficient), determines the time necessary for the purification, according to the concentration of the sewage and the B.O.D. of the purified liquid. This time cannot be reduced by the intensification of the aeration process.

H. W. STREETER

DETECTION AND MEASUREMENT OF STREAM POLLUTION

By M. M. ELLIS

U. S. Bur. Fisheries, *Bull.* **22**, 365–437 (1937)

The natural inherent water conditions of most streams can be ascertained for pollution studies regarding fisheries problems by determining repeatedly at different times by night and day the dissolved oxygen, pH, ionizable salts, free and fixed CO_2, total NH_3 and suspensoids. Minimum D. O. values approximate 5 p.p.m. The extreme range of pH found in U. S. inland waters containing fish was 3.9–9.5, the general range being 6.3–8.6 for lowland streams whereas mountain streams were more acid. Specific conductance offers a ready method for detecting salt and acid pollution as produced from oil wells, mines, wastes from industries and by solutions of heavy metals. If the specific conductance exceeded 1,000 mhos. in streams, except in the more alkaline regions, pollution was indicated. In alkaline waters the critical value was 2,000 mhos. Free CO_2 exceeding 3 cc. per liter was indicative of pollution in inland streams. Iron more than 100 p.p.m. was associated with superacidity and often chemical or mine pollution was found. Iron as found in streams is not a major limiting factor for fishes, 100 p.p.m. not being harmful to fishes or *daphnia*. Approximately 1.5 p.p.m. of dissolved NH_3

in fresh waters was considered the maximum amount not suggestive of organic pollution. Some acclimatization to NH_3 is possible, some species of fish life being found in the presence of 3 to 10 p.p.m. In flowing streams 2 to 3 p.p.m. are always associated with pollution and more than 3 p.p.m. are always traceable to sewage or industrial wastes.

Suspensoids consist of erosion silt, organic detritus, bacteria and plankton. Silt causes turbidity and prevents light from penetrating water. In unpolluted streams favorable to fish the millionth intensity depth, *i.e.*, the level at which light entering the surface would be reduced to one-millionth of its surface intensity, is 50 meters or more. The silt load of streams favorable to fish life should be reduced so that the millionth intensity level should be not less than 5 meters. Sixty-five per cent of the inland streams of the U. S. have summer water temperatures of 22° to 30° C. Mountain and headwater streams are 10° to 15° in summer.

Among the other topics discussed are the flora and fauna of polluted and unpolluted streams, lethality tests with fish and plankton with toxic limits of various substances, and the specific effects of 30 types of industrial waste on fish and on physical and chemical composition of water.

H. W. STREETER

THE ROLE OF ENZYMES IN ACTIVATED SLUDGE AND SEWAGE OXIDATIONS

BY W. R. WOOLDRIDGE AND A. B. STANDFAST

Biochem. Jour., 30, 9, 1542–1553 (1936)

Evidence is presented that the most important factor in biological oxidations of sewage is a series of catalyzed oxidation-reduction reactions determined by bacterial enzymes, present in either living or dead bacterial cells, or liberated by them into the fluid of the reacting system. Crude sewage, sterilized by heat, or by various disinfectants, does not usually absorb oxygen. Autoclaved sewage does not absorb oxygen, even on vigorous aeration. Addition of a seeding of crude sewage, a suspension of washed sludge, a suspension of washed bacterial cells, or a suspension of bacteria-free protozoal cells, induces the oxidation of sterile sewage or sterile sludge. Some species of bacteria oxidize sterile sewage rapidly; others slowly. The two species of protozoa examined proved less active than most bacteria.

Urethane (5 per cent) inhibits oxidation of sewage and sludge. Cyanide M/200 to M/10,000 KCN, neutralized (or vapor from solid KCN) inhibits the uptake of oxygen by crude sewage and by sludge, but inhibition is not complete and lessens with time, presumably due to alteration of the cyanide. Bacteria, carefully treated with formaldehyde, though unable to proliferate in the usual culture media, can induce slow oxidation of sterile sewage. Sewage sterilized by ultra-violet, will still absorb oxygen on shaking with air provided the irradiation is not too severe. Oxidation of sewage depends generally on the presence of certain oxidative enzymes (dehydrogenases and oxidases) of micro-organisms. These enzymes may be effective whether the organisms are alive or dead, provided that the method of killing has not destroyed the enzymes. Although protozoa possess enzymes that can oxidize sewage, most of the oxidation is caused by bacterial enzymes, the bacteria being more numerous and active. The enzymic activities of living and dead cells have not been directly compared, but the activity of the living cell is probably greater than that of the dead cell. The dead cell is important in oxidations by activated sludge as the sludge is likely to contain a large proportion of dead bacterial cells, many of which are probably enzymically active.

H. W. STREETER

RELATIONSHIP BETWEEN TURBIDITY MEASUREMENTS AND B.O.D. AND SUSPENDED SOLID DETERMINATIONS

By W. Watson and E. McG. Weir

Abstract, *The Surveyor*, 92, 43–44 (July 9, 1937)
Discussion, *The Surveyor*, 92, 207–209 (August 13, 1937)

While the B.O.D. test gives the best indication of the effect of normal effluents on a stream, it presents the serious disadvantage to the plant operator of requiring 5 days for completion of the test. A large series of experiments comparing turbidity measurements with B.O.D. at the Burnley Sewage Disposal Works have indicated that, by measuring the turbidity, the B.O.D. may be estimated within 5 per cent for 70 per cent of the samples. Only 10 per cent of the estimated B.O.D.'s were over 10 per cent in error.

The apparatus used for turbidity measurements consisted of a 1¼ in. brass tube, 30 in. long, in a vertical position, with a small overflow reservoir. The bottom is covered with clear glass and a slotted tinfoil disk is provided, which under illumination gives slot images. This tube is filled with the sample and a 1⅛ in. brass tube with a clear glass bottom, the "plunger," is raised or lowered in the sample until the images disappear and the field of view is uniformly illuminated. The reciprocals of the tube depths measured, plotted against B.O.D. determinations, give a straight line graph. To overcome variations in intensity of light source and the necessity of recalibrating the apparatus, twin tubes of similar construction to the first turbidimeter and with a common light source, have been used. Turbidity-free water is placed in one tube and the illumination on this tube is decreased by means of wire gauze a constant amount, generally about 80 per cent. The apparatus is then calibrated by placing the sample in the other tube and moving the plunger until the intensity of the transmitted light is equal. Color filters are required for some samples.

Promising results in eliminating the human factor were obtained by the use of photoelectric cells. The best arrangement tried consisted of two cells of the selenium-iron rectifier type wired in opposition to each other with a microammeter and variable resistance connected across them. Parallel beams of light of equal intensity were passed through identical glass-ended vessels, 10 cm. being used for effluents and 1 cm. for settled sewages. The apparatus is calibrated by balancing the system while both vessels are filled with distilled water, then adjusting the resistance to give a reading of 100 on the microammeter when all light is eliminated from one photoelectric cell by means of a shutter. Any liquid placed in the vessel of this side will then give readings of 0 to 100 depending upon its turbidity. Experiments on the effect of color have been planned, including the use of a sodium vapor lamp as the light source.

Discussion.—Mr. W. D. Scouller (Huddersfield) stated he had used a turbidity test as an indication of plant performance with good results for about ten years, but believed that the apparatus would require calibration at each sewage works. He questioned the authors as to the linear graphs obtained in correlating B.O.D. and turbidities of effluents, whereas the graphs for settled sewages and contact bed effluents were slightly curved. Dr. Watson could not explain this difference for settled sewage, but thought that the curved graphs obtained with contact bed effluents were due to the presence of relatively untreated settled sewage.

Mr. W. T. Lockett (West Middlesex) mentioned similar experiments recently reported by Professor Stroganov of Moscow, Russia. The Russian investigator had tried several colorimetric methods and had devised a method for testing the coarse suspended solids with a chromatic net which had given satisfactory results. He considered turbidity measurements of more value for the indirect determination of suspended solids than for B.O.D., but felt that more work was necessary in order to determine whether turbidity measurements would give reliable information on the B.O.D. of sewage and effluents. He pointed out that clear solutions such as sugars and phenol could alter the B.O.D. tremendously without affecting the turbidity.

Mr. J. M. Wishart (Shipley) gave figures which showed that, based on turbidity, the percentage purification was consistently less than when based on either B.O.D. or suspended solids removal. He had been experimenting with a photoelectric apparatus having one cell, and questioned the advantages of complicating the apparatus by introducing a second cell. A reading of 100 on the microammeter of his (Mr. Wishart's) apparatus was obtained by varying the opening of an iris diaphragm while distilled water was present in the glass cell, then, without changing the settings, the distilled water was replaced with the sample and the reading on the microammeter was then a measure of the transmitted light on a scale of 0 to 100. His apparatus was patterned after one used by Glenn W. Holmes and reported in the Sewage Works Journal for July, 1935. He (Mr. Wishart) confirmed Mr. Holmes's conclusion that the fineness of the suspended matter had a big effect on the results, more uniform results being obtained on comminuted sewage. He also preferred the use of the term percentage of light transmission since, as pointed out by Holmes and others, absolute turbidity values would require calibration of the apparatus with some standard substance such as fuller's earth.

R. W. KEHR

THE RENAISSANCE OF THE PERCOLATING FILTER

BY H. N. JENKS

* Abstract, *The Surveyor*, 92, 5–7 (July 2, 1937)

The biofilter plant comprises essentially one or more detention tanks having a holding capacity corresponding to that of activated sludge aeration tanks, a similar number of shallow depth percolating filter beds, arranged for stage working, and a system of recirculating the liquid between the tanks and beds. Biofiltration permits working the beds at eight to ten times their normal rates, and its flexibility enables any desired degree of purification, up to that obtained by activated sludge, to be maintained. The high rate of flow of liquid through the filter, combined with the better natural ventilation of shallow beds, maintains aerobic conditions and gives a continuous flushing action which presents clogging. The period of detention and recirculation in biofiltration is analogous to activated sludge aeration and, through this introduction of a definite time element, the process becomes dynamic instead of static as it has previously been. The high rates of filtration supply the organisms with an abundance of food demanded by their greatly stimulated activities. As pointed out by Kessener and Ribbius, the first part of Phelp's law infers that the return of sludge in a biologic purification system not only furnishes the required microorganisms and absorption surfaces, but is, in addition, a supplier of oxygen-demanding constituents. The latter part of Phelp's law indicates that there is an optimum dissolved oxygen content for activated biologic life. In the biofilter, great efficiency results from a proper "loading" of the bed with oxidizable organic matter, but whether this should be supplied by additional return sludge or higher rates of filtration requires further research. Higher rates of filtration have proven satisfactory, but it may prove more economical to return sludge.

In a trickling filter a definite zoning of organisms takes place from top to bottom. Bioprecipitation occurs largely in the upper half which is concerned with ammonification, and the sloughings tend to clog the lower zone and impair purification throughout. Nitrification occurs in the lower half of the trickling filter bed and requires a longer detention period which implies greater surface area and therefore smaller sized filter medium in the lower than in the upper half. Due to clogging and ventilation difficulties, use of finer rock in the bottom half is not practical with conventional filters and separation of the filter into two stages is not economical. With the high-speed biofilter, however, stage treatment not only becomes practical but tremendously increases the scope and versatility of the process itself.

* Presented at the Annual Conference, Institute of Sewage Purification.

Biofilter depths range from 2 to 4 feet, being about 3 feet for sewage of 200–300 p.p.m. B.O.D., under which conditions an 18–24 m.g. per day rate is desirable, with 12 and 30 m.g. per day as the extreme ranges for strong and weak sewage respectively. The size of rock does not condition the degree of purification so much as the time required to attain it. In one series of tests, 78 per cent B.O.D. reduction was attained in one hour with ½–¾ in. rock, whereas five additional hours were required to effect the same removal with rock of 1½ to 2½ in. size. In practice the best rock sizes were found to be 1½ to 2½ in. for single stage or the primary beds of two-stage treatment, and ¾ in. to 1 in. for secondary stages, with both stages of about equal volume. Detention periods should aggregate from 4 to 6 hours, increasing up to 12 hours for trade wastes of 1,000–2,000 p.p.m. B.O.D. Experience has consistently demonstrated that there is efficient sedimentation in the detention tanks.

Over a broad range, up to 6, of the ratio of rate of recirculation to rate of sewage flow, the B.O.D. removal in pounds per day per cubic yard of filtered rock is in practically direct proportion to this ratio. Quite strong sewages and industrial wastes require ratios in excess of 6, but the total rate of application should not exceed 120 m.g. per acre per day, in any event.

The plant site for biofiltration need not be isolated and the area required is less than one-fourth that required for percolating filters. Construction costs do not greatly exceed those for an activated sludge plant, and operating costs should approximate one-half those of an activated sludge plant. The pumping costs for power can be accurately computed in advance.

Discussion.—Mr. J. H. Garner (West Riding Rivers Board), who read the paper in the absence of Mr. Jenks, pointed out certain similarities between biofiltration and the Sheffield bio-aeration process. Mr. Garner also referred to treatment with high rates of flow through percolating filters as being partly the basis of Mr. Jenks's work. In these experiments, clogging, which might occur at rates of 7–10 m.g. per acre per day, disappeared when the rate was increased to 20 m.g. per acre per day, with little falling off of the percentage purification. The recirculation and dilution features of bio-filtration were not new, having been used as early as 1904 by Dr. Fowler at Manchester and a little later at Bradford in the treatment of gas liquors.

Mr. J. Hurley (Wolverhampton) criticized the comparison of the flushing action of high rates of flow with backwashing of filters, since in the latter case the direction of flow was reversed. He did not think the return of sludge to provide oxidizable organic matter for the filter would be necessary, particularly in England where stronger crude sewages would supply the necessary demand. Regarding the rates of filtration used, he pointed out that where a 21 m.g. per acre per day rate had been given for a relatively weak sewage, with double filtration, the actual rate of application of 12 m.g. per day, being filtered twice, was the equivalent of 6 m.g. per day on a conventional trickling filter. He thought the economic advantages of the method over conventional trickling filters would largely disappear when the power operating costs and the construction costs of the detention tanks were considered. Experiments were under way at Wolverhampton using forced ventilation of enclosed trickling filters.

Mr. P. G. Lloyd (Kingston on Thames) remarked regarding the effect of temperature, stating that nitrifying organisms worked best at about 90° F., and he wondered whether their activity could be forced during the winter time. He questioned Mr. Jenks's conclusion that clogging of the bottom of a filter was due to anaerobic conditions, for he considered it due to the adhesive nature of the oxidized colloidal matter. He thought it desirable for some means to be developed to determine the most economical length of time which percolating filters could go without being cleaned. On one occasion beds which had been cleaned by removing the rock and washing were able to handle 50 per cent more tank effluent than uncleaned beds.

Lt. Col. F. C. Temple (India) concluded from his experience with increasing the volume of return activated sludge that "there was a lot to be said for passing the stuff round and round," but did not see how recirculation of the effluent could increase the food supply and was of the opinion that it would merely add more clogging material.

R. W. KEHR

Book Review

Vom Wasser XI, Yearbook of the Water and Sewage Group of the German Chemical Society. 1936. Edited by L. W. Haase. Verlag Chemie, Berlin W 35. 15 Marks.

This annual volume of the water and sewage group of the German Chemical Society is a valuable source of information for water and sewage chemists in all countries. This, the eleventh volume, contains twenty papers, of which only six deal with the treatment of sewage or industrial wastes. It seems rather surprising that a year's progress in sewage treatment in Germany should result in only six articles by the chemists and engineers of this group. However, the six contributions are presented by well-known and competent men, namely, Sierp, Heilmann, Haase, Strell, Furkert and Mahr. These papers are as follows:

Dr. F. Sierp's paper, "Fat in Sewage Technique," deals with the character and amount of fat in sewage, fresh sludge and digested sludge. Tables and curves are presented to show the effect of various extraction solvents. A few references are given to attempts that have been made to extract grease from sludge (no reference to the Miles Acid Process). A comparison is drawn between fat recovery and production of gas by digestion of such fat, and it is concluded that the latter is economically preferable. The question of soap conservation is discussed with respect to water softening. Reference is made to experimental studies at Witten on the production of fatty acids from coal. Five pages of discussion follow the paper.

Dr. A. Heilmann, Editor of *Gesundheits Ingenieur,* contributes a paper of 15 pages on "Drainage, Sewage Treatment and Sewage Utilization in Germany in the Year 1935." He gives four pages of definitions and formulae used in sewage work. A review of German progress in sewage treatment in 1935 follows. Special attention is devoted to the use of sewage on land by spraying ("verregnung"), of which Dr. Heilmann has been an ardent advocate.

Dr. L. W. Haase, of the Landesanstalt at Berlin-Dahlem has a paper of 21 pages dealing with all phases of the chemistry of chlorination ("Chemisches von der Chlorung"). This is a very clear and interesting presentation of the subject.

Prof. M. Strell, of Munich, is the author of a short paper on the disposal of wastes from fermentation plants (breweries, distilleries, yeast factories, malt and diamalt, wine, and sauerkraut). This is a very general discussion and quite inadequate for the large field Prof. Strell has tried to cover. The discussion contains more data than the paper.

There is an interesting, though short, paper by Herbert Furkert, of the Munich Sewage Treatment Works, on the treatment of large volumes of distillery and tannery wastes in the activated sludge plant at Elmshorn. Experiments proved that the distillery wastes could not be handled in the plant and the author recommends its application to land, which seems a rather weak proposal for solution of the problem.

Dr. G. Mahr, now of the Wupperverband, but formerly of the Ruhrverband, has a paper of 8 pages entitled "Studies on the Self-Purification of Streams," which is mainly a review of Streeter's papers. In the 8 pages of discussion, Dr. Husmann describes the work at Zurich in experimental channels, for studying the self-purification of water from the Limmat. Further discussion was contributed by Dr. Stoof on the prevention of growth of *Sphaerotilus* by lining the banks of a small river with copper-slag; by Dr. Heilmann on the economic value of streams and lakes in the disposal of sewage; and by Dr. Imhoff on the biological and engineering features of lakes and ponds which receive sewage effluents.

The additional papers deal with water chemistry, water purification and softening. An amusing paper by Dr. Splittgerber discusses the use in Germany of "Tonisator"

bulbs, called "scale buoys" in England. These are glass bulbs partly filled with mercury and a rare gas (neon), sold to prevent formation of scale in boilers. G. Ammer, of Essen, is reported to have had a specialist "dowser" determine the changes in "tonisated" water with his divining rod.

The volume of 293 pages closes with a brief review of books and monographs dealing with corrosion and water chemistry.

F. W. M.

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